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A Review of Factors Affecting the Efficiency and Output of a PV System Applied in Tropical Climate

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Abstract. The awareness of people and government toward the use of renewable energy for electricity generation has increased the application of PV system to power houses and offices. The environmental merits of PV system also add to the benefits gained from this direct conversion of solar energy into electricity. The remote islands located far from government's electricity generation can have an alternative electricity source from PV systems. However, the efficiency and output of a PV system are affected by some factors including environmental factors found in the tropical climate. Indonesian climate both gives advantages and disadvantages to the electricity efficiency and output of a PV System. High temperature and humidity, dust accumulation, and sea salt effect are among of the environmental impacts of Indonesia's tropical climate and topology. This paper is a review study on factors affecting the efficiency and output of a PV system applied in the tropical climate. This study is based on a literature review and analysis of PV system installation in some places in Palembang and remote areas near Palembang. This study gives a recommendation to encounters the environmental disadvantages of PV system application in the tropical climate. This study recommends the factors need to be address when applying the PV system in tropical climate.

Keywords: Output and efficiency, photovoltaic system, renewable energy, and solar power plant

1. Introduction

People and government awareness toward the decrease of fossil fuels and the pollution caused by the utilization of the conventional power plant raise the application of renewable energy as a green alternative in Indonesia. Indonesia as a country located in the equator that has abundant of sunlight. Therefore the Solar Power Plant is by far a potential alternative for Indonesia. It is not only useful in making use of unlimited energy resource from the sun but also decreasing the CO₂ emission that promises a better life for our descendants [1].

Even though Solar Power Plant seems to be the answer for the shortage of conventional fossil fuel, the Photovoltaic (PV) panels as the main electricity generator still have to deal with the issue of efficiency. By theoretical analysis, the highest energy efficiency possible of PV panels is only 29%, and for the commercial product, it is just up to 26%. Therefore, the efficiency is the main issue in implementing PV system. Six factors are affecting the efficiency of the PV system, starting from cable thickness, temperature, shading, charge controller, inverter, and battery. These six factors have to be carefully considered while designing a PV system to achieve optimum efficiency [2][3].



The first factor is cable thickness. The house appliance in Indonesia is 220V, while the produced DC voltage by PV system is 12-48V, therefore for the same wattage, the higher current exists in the system, and thus resistance gets higher [4][5].

The second factor is the temperature generated in PV system due to. It is understood that sunray is the source needed for generating electricity by PV system. However, more sunrays mean higher temperature, and despite its requirement of the amount of sunlight, the temperature affects the PV panel's efficiency. The ideal temperature of a PV panel is 300^oK. If the temperature is more than 300^oK, then the panel output is reduced by 0.25% for amorphous cells and 0.4-0.5% for crystalline for each degree increment. To avoid the overheated solar panel, a cooling system is used, by using passive or active cooling system [6]-[11].

PV effect is the direct conversion of sunrays into electricity, at the real-time, and supposed something comes up above the panel (shading), the output power will be affected immediately. Shading can be temporary, such as the flying bird or the falling leaves, or add up through time such as dust accumulation [12]-[21]. Cleaning the panel regularly and installing it without any permanent shading from the trees or building can be the solution [22][23].

There are two types of PV system connection, the off-grid (standalone) and on-grid. Off-grid means the PV system supplies it load without support from other grid utilities. In this case, the system needs battery and charge controller to power the load without any power shortage during the cloudy days and to save the energy produces at daytime. A charge controller is needed as the safety during battery charging to ensure no overcharging and overvoltage [23]-[27]. The latest technology in charge controller is maximum power point tracking (MPPT) that keeps the panel in its maximum voltage and at the same time produce the voltage required by the battery. The on-grid connection is that the system connected to grid utility, in this case, battery and charge controller application are not necessary. However, the synchronization between both electricity sources is needed, and it inevitably brings another efficiency issue. PV system produces DC voltage. However, most of the customer loads use AC. Therefore, inverter is needed, but its efficiency is less than 100% [28]-[26].

This paper is a review study on factors affecting the output and efficiency of solar panel for solar power generator in the tropical climate. This paper discussion is based on literature study and analysis of PV system installation in some places in Palembang and remote areas near Palembang, South Sumatra, Indonesia. This study gives a recommendation to encounters the environmental disadvantages of PV system application in the tropical climate.

2. Overview of a PV system

Solar panels convert sunlight into electricity directly. The sun radiation comes to the earth in the form of the photon moving in the electromagnetic wave. As the light hits the solar cell, the electrons (negative charge) in semiconductor material get excited and leave the holes (positive charge). The energy brought by photon has to be higher than the semiconductor's energy band gap, to ensure the electron to be able to cross between junctions. The higher energy comes from the absorbed light, the more electrons movement created. As the electrons move, the charge is carried and electricity produced. The more extended electron movements are, the more electricity generated. Since there is a tendency of electron goes back to its hole (recombination), it is desirable solar cell material to support the electron-hole pairs life-time. If the carrier (electron) recombines, then the electron-hole pair is lost, and no power is generated anymore. Figure 1 shows the systematic diagram of a PV system, and each component mentioned in fig. 1 gives the contribution to decreasing the efficiency.

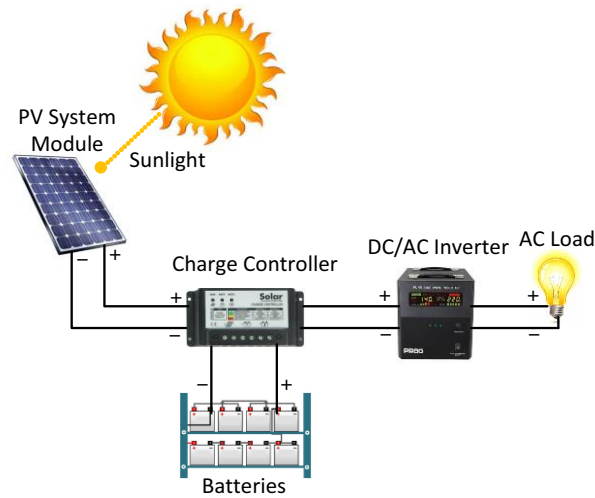


Figure 1. PV system schematic diagram

3. Effects of Cable Resistance

Cables are important in the electricity system, however, it also one of the sources of energy losses. In the PV system, losses due to wires are DC losses in the string of solar panels and AC losses at the output of an inverter. Voltage drop in a cable is given by

$$\Delta V = b \left(\rho_1 \frac{L}{S} \cos \varphi + \lambda L \sin \varphi \right) I_B, \quad (1)$$

where V is the voltage (phase-phase voltage for 3-phase, and phase-neutral voltage for single-phase) and ΔV is the voltage drop, b is the cable length factor, L is the length of the cable, S is the cross section of cable in mm, $\cos \varphi$ is the power factor and $\sin \varphi = \sin(\arccos(\cos \varphi))$, λ is the reactance per length unit, I_B is current in A, and ρ_1 is resistivity in ohm.mm²/m for a given temperature.

The value of ρ_1 in eq. 1 is calculated from

$$\rho_1 = \rho_0 (1 + T_C(T_1 - T_0)), \quad (2)$$

where ρ_0 is resistivity at T_0 ($T_0 = 20^\circ\text{C}$), T_C is temperature coefficient per degree in Celsius, T_1 is cable temperature (default is at 100°C).

Cable heating is inevitable in its application, the heat increases its resistance and in the end, causes the energy losses. The energy losses in a cable due to resistive heating is

$$E = a \cdot R \cdot I_B^2, \quad (3)$$

where E is energy losses in cables (Watt), a is number of line coefficient ($a = 1$ for single line and $a = 3$ for 3-phase circuit), and R is resistance that is given by

$$R = b \cdot \rho_1 \cdot \frac{L}{S}. \quad (4)$$

Gan et al. 2014 presented an optimization approach in determining optimal rating of PV cable design by taking account of total cost and losses through PV system lifetime. The heuristic approach of electricity prices validated the result of the proposed method. The paper recommended to oversize the designed cable to minimize the losses in the long run [4].

Malamaki et al 2014 presented the analysis of annual energy losses on DC and AC cables based on some unknown parameters estimated from the equipment data sheet. The analysis is to give the recommendation for design engineering in comparing different cable crosses section. The validity of the proposed method was tested against the measurement of 2 existing PV systems in Greece [5].

4. Temperature Effect on PV system

PV panel consists of a number of solar, and solar cell material is a semiconductor. Semiconductor devices are sensitive to temperature changes, as it will act as an insulator during the cooled down and as a conductor when heat up. However, the temperature standard to generate optimal power output is 300°K or around 25°C. When the PV system is applied in a hot climate such as Indonesia, the silicon cell temperature can easily reach pass the ambient temperature. As a silicon solar cell is overheated, it generates more current and less voltage, the voltage drop occurs, and the generated power decreases.

The calculation of maximum point power, current and voltage is given in I-V curve characteristic in figure 2 and calculated as below

$$P_{mp} = I_{mp} \cdot V_{mp} = FF \cdot I_{sc} \cdot V_{oc}, \quad (5)$$

where P_{mp} is the maximum power, I_{mp} is the maximum current, V_{mp} is the maximum voltage, FF is fill factor, I_{sc} is short circuit current, and V_{oc} is the open circuit voltage.

IV-Curve is defined by I_{sc} and V_{oc} . I_{sc} and V_{oc} related to solar cell modeling as an ideal diode, and are the maximum current and voltage produced by the solar cell. If both at the operating points, then the power generated is zero. The parameter that connects I_{sc} and V_{oc} is called FF and it determines the maximum power produced by the solar cell. In figure 1, A area is the cell with lower fill factor, and B area is a cell with higher fill factor.

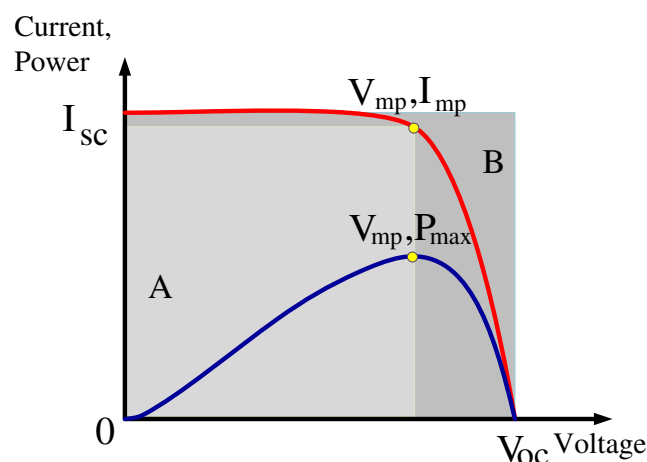


Figure 2. I-V Curve

Dubey et al. 2012 [6] derived the relation between temperature rises and power production

$$\eta_c = \eta_{T_{ref}} [1 - \beta_{ref}(T_c - T_{ref})], \quad (6)$$

and

$$\beta_{ref} = \frac{1}{T_0 - T_{ref}}, \quad (7)$$

where η_c is the net efficiency of an applied PV module, $\eta_{T_{ref}}$ is the solar cell module efficiency at reference temperature T_{ref} , β_{ref} is the temperature coefficient, T_c is current solar cell temperature, T_0 is the highest temperature in which the efficiency of solar cell becomes zero [6].

The efficiency and output decrement due to overheated solar panels can be overcome by cooling the PV panels up to the ambient temperature 300K. The methods of cooling PV panels are by passive and active cooling methods. A passive cooling method is by naturally cooled down PV panels without consuming power, such as letting the cold wind blow on PV panels or the installation of a heat sink with different rib's angles. An active cooling method is conducted by using additional devices to cool the PV panels down, such as by using a pump to flow water above the panels. Therefore this method consumes power.

Wu et al. 2014 studied rainwater as the cooling media and utilize a gas expansion device to distribute it over the PV cells. The authors discussed the design and simulation for house application by establishing the relationship among gas chamber size, solar radiation and gas expansion. To evaluate the proposed method, a heat transfer model was used and the results showed that the cooling device reduces PV cell temperature up to 8.3% [7]. Popovici et al. 2016 reduced PV panel temperature by installing heat sinks to cool the air down and were able to reduce the temperature by at least 10°C below the normal installation of PV panels. The efficiency was increased from 6.76% to 7.55% within rib angles of 90° to 45° respectively [8].

The cooling process is faster using the active cooling system, although some produced energy has to be sacrificed for it. The most used methods are fans to blow cooled air and pump to control the flow of water on PV panels. Amelia et al. installed four units DC fans to the backside of PV panels and reduced the average temperature up to 22.2% [9]. Misiopiecki C et al. 2012 let the air gaps between the roof and PV panels to ensure enough space for cooling down the PV panels [10]. Moharram et al. sprayed the PV panels intermittently to save the amount of water and energy. The PV panels were intended to be applied in Egypt desert, therefore saving water and energy is a remarkable fact, and the proposed method was validated by the experimental results [11].

5. Shading Effects on Solar Panels

Electricity generation using PV system is directly affected by the weather condition. During the sunny days, the produced power will be maximum, and sudden clouds shading will reduce the PV system efficiency and output. The shading factor is extended to anything that blocks the solar irradiance to the PV panels. The shading can be from the accumulated dust that in time will reduce the efficiency of the system. Partial shading has a significant effect on PV panels' production. The shaded cell absorbs electric power generated by the unshaded cells, and this condition caused the hot spots that can damage the PV panels.

The shading effect is modeled by Bishop Model to evaluate the power losses.

$$I = I_L - I_0 \left[\exp \left(\frac{V + IR_S}{n V_T} \right) - 1 \right] - \frac{V + IR_L}{R_{SH}} \left[1 + K \left(\frac{V + IR_S}{V_{br}} \right)^{-n} \right], \quad (8)$$

$$I_{SH} = \frac{V + IR_S}{R_{SH}} \left[1 + K \left(1 - \left(\frac{V + IR_S}{V_{br}} \right)^{-n} \right) \right], \quad (9)$$

where I and V are current and voltage, I_L is light current proportional to the received irradiance, I_0 is diode's reverse saturation current, I_{SH} is leakage current, V_T is the diode's thermal voltage, V_{br} is cell voltage breakdown, K is Bishop adjustment coefficient, n = adjustment coefficient, R is a cell series resistance, and R_{SH} is cell shunt resistance.

Dolara et al. 2013 presented the experimental study of the PV energy production losses under partial shading conducted in Solar Tech Lab of Politecnico in Milano. The experimental results provided the investigation of different shading scenarios to show the shadow effects on the electrical behavior of PV panels. The results become fundamental to derive the mathematical models for

evaluating the power losses under different irradiation conditions. At 50% shading, the experimental result shows that the output power reduced more than 30% [12].

Salem et al. 2015 presented a methodology for detection and assessment in PV panels using a neural network as the preliminary of automatic supervision and monitoring. The system is modelled under normal and partial shading condition. Two ANNs are applied, the first ANN is assigned to detect the partial shading, and the other one to determine the shading factor. The feasibility of the proposed method is validated by MATLAB simulation [13].

Mahammed et al. 2017 discussed the effect of partial shading by using Bishop model in Eq. 8 and 9. The proposed model is validated by the consistency between the measured and estimated I-V curve plots related to the power losses prediction due to different shading effect [14]. Wang Y et al. 2017 investigated the shading effect on roof-mounted PV panels, and the data were taken during the brightest day. The experimental results show the daily production of flat and tilted roof-mounted PV panels were reduced by 77.4% and 69.4%, and the energy efficiency decreased by 63.35% and 62.73%. Kanters et al. 2014 examined the technical and economical aspect of PV panels' mutual shading [15]. The experimental results showed that the array with row distance smaller than 1 m reduces efficiency more than the ones with higher row distances. The revenue of PV system installation was calculated by the amount of saved energy and money received by supplying electricity to the grid [16].

Nature has inevitable effects on PV system, such as soiling, especially for those panels installed in deserts. Soiling or dusting is considered as partial shading for having the same effect to reduce the output and efficiency of the PV system. Olivares et al. 2017 investigated the adverse impact of soiling on PV system performance installed in the Atacama Desert in northern Chile. They noted the variation of dust sizes of selected sites and the effects of PV panels, and after the four months or dust accumulation, the PV panel output reduces by 55% [17]. Menoufi et al. 2017 presented the evaluation of PV system performance installed on the east bank of the Nile, implemented in Beni-Suef University, Egypt [18].

Wang P. et al. 2018 proposed coating PV panels with fluorine super-hydrophobic film and silicon super-hydrophobic film to reduce the dust effect. Super-hydrophobic film coating increases the transmittance due to the micro-nano-antireflective structure that can improve the efficiency. The application of fluorine super-hydrophobic is more effective than silicon super-hydrophobic film [19]. Hammad et al. 2018 reviewed the implementation of PV system in the Middle East and North Africa in the case of Jordan related to the dust accumulation and ambient temperature. The authors proposed two models to simulate the effects and gave a recommendation of financial methodology on cleaning frequency; the first one is multivariate linear regression and utilizing the artificial neural network. The comparison of both methods was presented to show the validity of the proposed method. After 192 days of dusting, the average efficiency reduction achieved due to dust is 0.768%/day and 0.607% using MLR and ANN model respectively [20].

Tanesab et al. 2016 analyzed the economics due to dusting on PV panels installed in a mild temperature zone [21]. However, there is no recommendation of cleaning the PV panels, although some literature suggests it [22][23].

6. Charge Controller effects on I-V Characteristics

The produced voltage of every solar cell is about 0.5 V, and this production varies with light intensity, therefore to provide 12 volts, approximately 36 cells are required. The current continuously goes up to 18 volts and drops off rapidly when the voltage is more than 18 volts. The off-grid system needs the panels to be connected to the battery, and the produced voltage will be pulled down near the battery's standard voltage. Therefore, it is desirable that the battery is always in fully charged condition; however, this is not the normal condition of the battery. To keep the battery in its maximum voltage rate, an MPPT (Maximum Power Point Tracking) Charge Controller is required to improve the system efficiency. MPPT is also functioning as a DC to DC voltage converter with very little power loss by attempting to keep the PV panel voltage always near its maximum power point.

Mujumdar et al. 2017 designed a parallel MPPT for a PV system based on LED lighting implemented to a single stage on-grid. The designed MPPT controller ensured the maximum power

point operation by supplying deficit power between the loads through the on-grid converter. A LED lamp was functioning as the indicator to show the load suitability, and the constant voltage control ensured that the power converter maintains the stability without flicker during the heavy load. The proposed method was validated by experimental results [24].

Amine et al. 2015 designed fuzzy logic type 1 and 2 controllers for tracking the maximum power point. The fuzzy logic controller was tuned with a genetic algorithm (GA). GA tuning was found effective when the number of iteration was higher. However, it was time frame dependence within which the MPPT was calculated [25]. Phocos 2015 presented the difference of PWM and MPPT application in PV systems to ensure the maximum power point is tracked. MPPT has more charging efficiency and applicable to a large scale of PV system, while the PWM controller has longer life-span [26].

LokeshReddy et al. 2017 proposed a novel method for charge controller of PV system by using MOSFET for the switching purposes. This method is claimed to reduce the switching losses. The proposed method was validated by simulation in MATLAB/SIMULINK [27].

7. Inverter Efficiency Effect on PV System

PV system produces DC voltage while most of the home appliances are AC loads. Therefore, an inverter is needed. The problem is that there is no 100% efficiency in the real world, and inverter efficiency is around 80%-90%. For an on-grid system, an inverter is connected directly to the grid, and it has to track maximum power point (MPP) and converting DC current into grid's AC current. This conversion requires synchronization to be in the same voltage and frequency as the grid.

The PV inverters available in the market are classified by power, DC-related design, and circuit topology. The output power of the inverter range from 2 kWatt for private home PV plant up to 1 MWatt for PV power stations. The PV system module wiring to inverter can be in the string, and central inverter. Each string on multi-string inverter has its MPP tracker. The circuit topology is divided into one-phase for small plants and three-phase inverter for the power station. The most important characteristics of an inverter are its conversion efficiency indicated by the proportion of energy fed to the system and the output in the form of AC current. The inverter tasks are divided into

1. low-loss conversion
The modern inverter can convert up to 98%
2. Power optimization,
The IV curve of a PV panel depends on the received radiation intensity that changes continuously during the day. Due to this condition, the inverter must track the MPP all the times, and this is called power optimization
3. Monitoring and securing
Inverter monitors the output produced by the PV system and indicates any problems. It also monitors the connected power grid for the on-grid PV system. Therefore it is also equipped with safety devices that can immediately disconnect the PV system from the grid in the event of a problem on the grid. PV system is a continuous system. Therefore, the inverter is also always on.
4. Communication
An inverter is an interface to allow the control and monitor all of the parameters and operational data. Data is retrieved through a data logger installed on it.
5. Temperature management
The overheated inverter will reduce the produced power. Therefore the inverter system should include the cooling device such as a heat sink. The inverter with the included cooling device can work at maximum rated capacity up to 50°C.

Mary et al. 2017 modeled a 3-switch single-phase inverter for PV system. The contribution of the proposed method is using 3-switch instead of the conventional 1-switch. One of the switches is operating in high frequency, and the other two is in fundamental frequency. The feasibility of the proposed method is simulated in MATLAB/SIMULINK [28]. Madkor et al. 2015 presented the effect of the number of the inverter in the PV system. The paper showed that the number of inverters did not affect the efficiency but affecting system reliability and in the end would affect the system and cost.

The result showed that the most efficient is to implement one inverter. Two-axes tracking system with two inverters gave the highest energy, and this inverter was the most effective one in term of cost and efficiency [29]. Vignola et al. 2008 discussed the characteristics of the inverter and the problems that might be encountered [30].

8. Battery Efficiency Effect on PV System

The off-grid or standalone system requires backup storage due to the fluctuating produced power of a PV system, since PV system power protection relies heavily to how much irradiance falls on the PV panels. The most commonly used battery is the lead-acid type. The lifetime of a battery is far below the lifetime of PV panels. Therefore battery is a factor making the PV system more expensive. Energy requires to produce, and transport battery for a PV system is given by Rydh et al. 2005

$$E = \sum_{i=1}^5 E_i = \sum_{i=1}^5 \frac{Q_i}{t_i}, \quad (10)$$

where E is energy per year, $i = 1$ for PV array, $i = 2$ for charger, $i = 3$ for battery, $i = 4$ for inverter, and $i = 5$ for air conditioning.

The battery life is limited by

$$t_3 = \frac{N}{n} \sigma(T) \quad (11)$$

where N is the maximum number of charge-discharge cycles at 25°C, n is the number of charge-discharge cycle per-year, and $\sigma(T)$ is a time dependent correction factor [31].

Weniger et al. discussed the sizing of the battery converter for a residential PV system. The result showed that the small size battery converters at 1.5-2 W are the most suitable for residential PV system [32]. Haberschusz et al. 2017 investigated whether battery system was causing the ramping problem in German power grid [33]. Rai et al. 2018 implemented fuzzy logic control in controlling the duty cycle of the dc-dc boost converter to achieve the maximum power point tracking. The proposed method was validated by simulation in MATLAB/SIMULINK and showed that the application of fuzzy logic controller was more effective than the conventional PID controller [34]. Çinar et al. 2012 designed an intelligent charge controller system for controlling the MPPT to improve the efficiency of the PV panel storage system [35].

Kharseh et al. 2017 presented the optimal sizing of battery for multi-story residential building in the western part of Sweden. The optimal battery size resulting in the minimal payback time of a PV system was investigated in this system. The optimum size battery gave benefits in economic viability indicating by the earlier payback time of the PV system [36]. Litjen et al. 2018 implemented predictive control strategy to assess four PV systems. The authors modeled 48 residential and 42 commercial PV systems using a different combination of forecast method. The results showed that the predictive control strategy has higher storage revenue than real-time control that improves the self-consumption and reduces curtailment losses [37].

9. Factors Affecting Output and Efficiency of PV Systems Applied in Palembang

Palembang is situated in South Sumatra blessed with an abundance of sunlight through the years. The current power plant in Palembang relies heavily on conventional fossil fuel such as coal, diesel and natural gas. However, as fossil fuel is running out, Palembang's government searches for energy alternatives that not only substitute fossil fuel but also environmentally friendly to overcome the effect

of global warming. PV power plant becomes the best alternative. A 200 kW PV power plant is installed in Jakabaring Sports City to support electric supply during Asian Games 2018.



Figure 3. PV Power Plant in Palembang

The application of PV system in Palembang is effective with sufficient sunrays. PV panels can start to produce power from 08.00 AM to 05.00 PM with peak power at 12.00 PM. However the application of PV panels in Palembang prone to the reduction of output and efficiency, one of those factors is temperature. Although the annual average temperature is 27.5°C, the panel temperature can be up to 67.2°C. As it has been discussed above, the panel temperature over ambient temperature reduces the output and efficiency.

Some islands and the fishing villages such as Enggano Island near Bengkulu and Sunsang near Palembang can take benefit in PV power system. The best application for this rural area is the off-grid system. Unfortunately, the off-grid system requires the use of a battery, which has a short lifetime compared to the whole PV system. Another problem with onshore PV installation is that it has to overcome another form of shading by the sea salt dusting. This sea salt dusting not only becomes the partial shading but also corrosive for the balance of system (BOS).

The three most significant factors affecting the output and efficiency of PV panels installed in Palembang are temperature, shading, and battery. Other factors that might affect the output and efficiency can be overcome by the suggested method discussed in the previous sections. However, the limitation of PV power plant should not stop the application and development of PV system in Palembang. Up to the middle of 2018, there are two PV power plants in Palembang; the first one belongs to PERTAMINA (Perusahaan Pertambangan Minyak dan Gas Bumi or State Oil and Natural Gas Mining Company) Refinery Unit III since July 2017 with the capacity of 3x300 W and PLTS Jakabaring since June 2018 with the capacity of 2 MW.

10. Conclusion

The development and installation of PV Power Plant are increasing rapidly due to the government and people awareness for the decrement of conventional fossil fuel and the increment of air pollution that leads to global warming. PV System is the best alternative for a city with long period of sunshine along the year like Palembang. However, the output and efficiency of the PV power plant are still minimal. The best efficiency for silicon-based solar panels is 29% theoretically and less than 27% in reality. This low efficiency becomes less productive due to that every component installed in PV system is responsible for other losses. The contributors of the efficiency and output losses are PV panels' surface temperature beyond ambient temperature, shading, and battery for backup storage to the devices efficiency namely inverter, cable resistance, and charge controller. In Palembang, the panel surface temperature can be up to 67.2°C and for the rural area such as island and fishing village have to deal with sea salt dusting. Even though with a series output and efficiency challenges, PV system is

still the best alternative for a power plant in Palembang and the remote area around it since the sunlight is unlimited and environmentally friendly.

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