Sea Salt Deposition Effect on Output and Efficiency Losses of the Photovoltaic System; a case study in Palembang, Indonesia

Firdaus Setiawan¹, Tresna Dewi² and Syahirman Yusi³
¹ Renewable Energy Department, Politeknik Negeri Sriwijaya Palembang, Indonesia
² Electrical Engineering Department, Politeknik Negeri Sriwijaya Palembang, Indonesia
³ Business Administration Department, Politeknik Negeri Sriwijaya Palembang, Indonesia

E-mail: tresna_dewi@polsri.ac.id

Abstract. Indonesia is an archipelago country creating a challenging condition for the Indonesian government to distribute electricity evenly among the islands. The Indonesian government has encouraged the citizens to move from fossil fuel to renewable energy and targeted 23% of renewable application of energy mix in 2025 and 31% in 2050 following Government Regulation No. 79 of 2014. Indonesia is blessed with an abundance of sunlight to be harnessed and converted into electricity by a solar plant. One of the alternative applications of the PV system is a floating solar plant. However, the installation of the PV system near the ocean or off-shore endures sea salt effects. This paper presents the effect of sea salt deposition on output and efficiency loss of a PV system. Two modules are applied to simulate; one in a normal condition, another one splashed with sea water imitating the situation endured by the off-shore installed PV module. The case study is currently taking place in Palembang, South Sumatra, Indonesia, and the result of this research will be applied to a fisherman village near Palembang. The output measurement results show there were significant differences in production and efficiency. The average output power difference between the normal condition and salt doused PV module in three days is 1.3778 Watt, and the efficiency difference is 0.948. This number is significant considering the tests were taken for three days. The difference gap can be higher by longer time exposed to salt-containing environments.

1. Introduction
Indonesia is an archipelago country where its inhabitants are scattered across thousands of islands, and it is a challenging condition for the Indonesian government to distribute electricity evenly among the islands. The remote islands that are mostly inhabited by the fishermen and the fishing villages usually locate near the oceans. These remote villages rely upon diesel fuel and gasoline to power mini generator to get the electricity. The prices of these fossil fuels are costly, and only some can afford it. The dependency on fossil fuel soon will have to be stopped considering the source of fossil fuel will diminish in around 50 years. The Indonesian government has encouraged the citizens to move from fossil fuel to renewable energy and targeted 23% of renewable application of energy mix in 2025 and 31% in 2050 following Government Regulation No. 79 of 2014 [1][2][3].

On the other hand, Indonesia is situated in equator with an abundance of sunlight to be harnessed and converted into electricity. This potential power is very suitable for Indonesia geographical problems. The PV system can be installed individually or in a group inside the villages, and people can enjoy the electricity in a relatively easy way. The trending photovoltaic (PV) based electricity generation is happening worldwide due to the reduction of production cost of the PV module, the total
cost of installing Solar power electric generation also decreases. Some countries such as Japan and China have suggested the application of floating solar plant, and this idea can be implemented to the fishing villages in Indonesia [4]-[6]. Not to mention, the portability of PV solar plant, can be extended to power electricity for fisherman boats during the off-shore fishing.

However, the main problem of PV electric generation is the efficiency, and this already low efficiency can decrease more by some factors including excessive temperature [6], shading (full and partial shading) [7]-[12], and dusting[13, 24]. The application of PV power plant in a nearby ocean or the floating one comes with all three problems [14]-[20]. The surface temperature of the PV system can be way too high compared to the regular application in mountain or city area. The high-salt environment can cause damage in term of partial shading and dusting for the PV module, and the corrosive nature of salt can damage the balance of system (BOS) of PV power plant.

The metal in BOS can rust faster by being around salty air and water. The salt contamination in the air forms the acidic solution that causes corrosion including the wiring and metal part of BOS. The good thing is that the solar module is highly corrosion resistant due to the rigorous manufacture process, therefore as long as no crack in the sealing, the panel is safe from salty air [20]. The real problem comes from the salty atmosphere is the partial shading from salt crystal dusting. The accumulations of salt on the module affect the efficiency significantly. The effect of salt dusting is similar to other dust or dirt full and partial shading.

This paper presents the effect of sea salt deposition on output and efficiency loss of a PV system. Two modules are applied, one will be applied in normal condition, and seawater will be splashed to the other one will be doused with sea water imitating the situation endures by the off-shore installed PV module. The case study is currently taking place in Palembang, South Sumatra, Indonesia, and the result of this research will be applied to a fisherman village near Palembang.

2. Methods and experimental setup

2.1. Sea salt effect on PV modules

PV modules typically manufacture carefully to withstand the regular application of PV solar plant, starting from a series of solar cells are arranged and sandwiched between glasses, closed by encapsulated layer on both sides, and a backsheet closure is included. The arrangement is then laminated into one unit and framed by aluminum frame or frameless for new technology but still very safe closure [21]. Aluminum frames are functioning as edge protection from the environmental condition, mounting support to various substructures where the PV modules applied, and the possible glass breakage. Due to this good sealing manufacture, the sea salt is relatively not affecting the physical of PV module [16]-[20].

Dechthummarong et al. 2010 presented the physical deterioration of PV modules after a long-term application, i.e., 15 years, in Thailand [14]. The research results showed that the severe visual deterioration of 30x-Si modules was still within a limit of IEC standard. Mathiak et al. 2012 exposed PV modules under ammonia and salt mist condition and the test results also showed no significant effect on physical PV module [15]. Walsh et al. 2012 tested the impact of PV modules installed in Singapore tropical climate, and the results also showed that the modules passed the test [17]. However, the BOS is significantly affected due to the metal composition.

2.2. Sea salt effect as partial shading and dusting

The sea salt accumulation on PV modules gives the same effect as dusting and partial shading, due to the uneven distribution of salt deposits. This uneven spreading caused more accumulation in one spot rather than other parts of PV modules, and this condition can be considered as partial shading. Shading reduces the electricity production and efficiency of a PV module, and partial shading has a more significant effect on PV module, the shaded part or cell will have considerable temperature rise and failed in the cell. The failure cell can be a short circuit and affect the whole module. The application of bypass diode helps to overcome the problem by ignoring the broken cell.
The previous research showed that at 50% shading, output power decreased by more than 30% [7]. Salem et al. 2015 developed automatic supervision and monitoring using artificial intelligence [9]. Some research even got production decrement up to 63.35% and 62.73% [12]. The dusting or soiling of PV modules can reduce the output production by 55% by deliberately soiling the blades up to four months in the Atacama Desert in northern Chile [13]. The previous research showed significant losses due to shading and dusting, not to mention the accumulation of sea salt gives more effect than just a general dusting.

2.3. Experimental setup

This paper discusses the effect of sea salt accumulation on the PV module regarding output production and efficiency. This study compares the output power and efficiency between a normal PV module application, shown in fig. 1, with the PV module covered by salt accumulation. The PV cell considered in this research is multi-crystalline silicon and table 1 shows the specification technique of the installed PV module in this study, manufactured by Sankelux.

The specification techniques of the installed PV module are the variables used to calculate the maximum power output ($P_{max}$) and efficiency ($\eta$), given by

$$P_{max} = V_{oc}I_{sc}FF,$$

$$\eta = \frac{V_{oc}I_{sc}FF}{P_{in}}$$

where $V_{oc}$ is the open circuit voltage in volt, $I_{sc}$ is the short circuit current in ampere, $P_{in}$ is the input power, and $FF$ is the fill factor given by

$$FF = \frac{V_{MP}I_{MP}}{V_{oc}I_{sc}}$$

where $V_{MP}I_{MP}$ is the maximum power point [22]. Therefore the I-V curve based on table 1 and eq. 1 to 3 is shown in figure 1.

| Parameter | Units | Value |
|-----------|-------|-------|
| $P_{max}$ | Watt  | 100   |
| $V_{MP}$  | Volt  | 18.74 |
| $I_{MP}$  | A     | 6.20  |
| $V_{oc}$  | V     | 22.04 |
| $I_{sc}$  | A     | 6.57  |
Figure 1. The I-V curve of the installed PV module.

Figure 2 shows the experimental set-up for investigating the effect of sea salt on the output and efficiency of the PV module. Two modules are installed side by side to get the same condition and environment. The PV module in fig. 2a is the investigated PV module, subjected to be doused every hour from 07.00 AM to 04.00 for 16 days (from August 1 – 16, 2018). The objective of soaking the PV system in every hour is to accelerate the accumulation of salt on the surface of the PV module. The splashed sea water will be evaporated and leave the crystal dust as the partial shading to the PV module. The PV module in fig. 2b is in the standard application for comparing the effect of sea salt accumulation.

Figure 2. PV module setup application.
(a) Sea salt doused module, (b) Normal application

Figure 3 shows the measurement setup and both PV modules are connected to 100 watt DC lamp as the load. The system connected to Voltmeter and Amperemeter to measure the output voltage and current. The incident solar radiation per unit area is measured by a solar power meter.
3. Result and Discussion
Figure 4 shows the sea salt crystal accumulation on the surface of the PV module shown in fig. 2a after 16 days of dousing for every hour from 07.00 AM to 04.00 PM. PV module output measurements were conducted in 3 days, August 15-16, 2018. Figure 5, 7, and 9 show the output power measurement results between the typical application and doused with sea salt. Figure 6, 8, and 10 show the weather forecast from August 15-16, 2018.

Figure 5 shows that the output result from the normal condition of PV module is more than the one with sea salt accumulation on its surface. For example at 18.12 AM the salt dusted PV module has the output 27 watts while the normal condition is 30 watts, and the highest power was accumulated at 10.13 AM with the output power of 45 watts for the normal state, and 35 watts for the salt dusted module.
On August 14, 2015, the peak production was at 10.13 AM since, after that time, the day was cloudy during the supposed to be peak hours of the day. The output result affected by weather condition is confirmed by fig. 6. The temperature on August 14, 2018, was ranging between $25^\circ$C to $34^\circ$C with the lowest humidity was 50% at 02.00 PM.

On August 15, the day was relatively sunny with temperature from between $25^\circ$C to $33^\circ$C, and the humidity was 50% to 95%. There was an output drop at 09.27 AM and turned out there was a bird perched on top of PV panels so that the standard output was disrupted. The output power was at the highest from 10.19 AM to 03.15 PM. The highest production was at 12.28 PM with the output of 37.16 Watts for normal condition and 36.08 Watts for the salt dusted module. The output and weather condition on August 15, 2018, is comparable by observing figure 7 and 8.
The weather was sunny in Palembang on August 16, 2018, as shown in Fig. 9. The temperature form 06.30 AM to 05.30 PM was ranging from 24°C to 33°C. The highest irradiance on both PV modules was 1,119.90 W/m² at 11.28 AM. On 09.27 AM, there was cloud shading that affects the output result, however starting from 10.12 AM, the weather was sunny causing a stable electricity generation.
Indonesia was in dry season during the measurement tests. Therefore the weather was very conducive for the PV system. The average output power difference between the normal condition and salt doused PV module in three days is 1.3778 Watt. This number is significant considering the measurement tests were only taken for three days. The difference gap can be higher by longer time exposed to salt-containing environments.

Figure 11 shows the efficiency comparison between the standard application and salt dusted panels. The green line in figure 11 indicates the efficiency difference, and averagely the difference was 0.948. Table 2 shows the recapitulation of the output and efficiency comparison from 3 days measurement.
### Table 2. Output power and efficiency of 3 days measurements.

| Date         | Time  | PV module with normal application | PV module with salt accumulation |
|--------------|-------|-----------------------------------|----------------------------------|
|              |       | $P_{in}$ | $P_{max}$ | $\eta$ | $P_{in}$ | $P_{max}$ | $\eta$ |
| August 14, 2018 | 07.16 | 11.44     | 0.65      | 0.06   | 7.97     | 0.36      | 0.05   |
|              | 08.08 | 40.13     | 29.81     | 0.74   | 38.65    | 27.14     | 0.70   |
|              | 09.17 | 49.70     | 37.23     | 0.75   | 48.38    | 35.47     | 0.73   |
|              | 10.10 | 96.85     | 46.14     | 0.48   | 95.75    | 34.38     | 0.36   |
|              | 11.08 | 48.24     | 29.21     | 0.61   | 46.58    | 27.10     | 0.58   |
|              | 12.11 | 80.04     | 27.40     | 0.34   | 77.81    | 25.31     | 0.33   |
|              | 13.08 | 105.27    | 36.69     | 0.35   | 102.99   | 35.55     | 0.35   |
|              | 14.08 | 25.85     | 37.89     | 1.47   | 24.82    | 36.38     | 1.47   |
|              | 15.08 | 68.52     | 35.69     | 0.52   | 66.77    | 33.85     | 0.51   |
|              | 16.13 | 19.34     | 8.77      | 0.45   | 18.69    | 7.75      | 0.41   |
|              | 17.04 | 11.10     | 0.61      | 0.06   | 10.60    | 0.50      | 0.05   |
|              | 06.34 | 2.68      | 0.02      | 0.01   | 2.36     | 0.02      | 0.01   |
| August 15, 2018 | 07.11 | 11.04     | 0.81      | 0.07   | 10.78    | 0.68      | 0.06   |
|              | 08.29 | 45.89     | 33.52     | 0.73   | 44.70    | 30.96     | 0.69   |
|              | 09.27 | 33.73     | 25.19     | 0.75   | 32.75    | 30.08     | 0.92   |
|              | 10.13 | 95.82     | 36.63     | 0.38   | 93.81    | 35.40     | 0.38   |
|              | 11.08 | 108.61    | 37.02     | 0.34   | 106.61   | 35.81     | 0.34   |
|              | 12.25 | 113.92    | 37.14     | 0.33   | 112.06   | 36.08     | 0.32   |
|              | 13.18 | 105.56    | 37.16     | 0.35   | 103.12   | 35.78     | 0.35   |
|              | 14.03 | 100.12    | 36.20     | 0.36   | 98.06    | 35.20     | 0.36   |
|              | 15.11 | 73.59     | 35.40     | 0.48   | 71.69    | 33.91     | 0.47   |
|              | 16.29 | 34.48     | 8.22      | 0.24   | 33.25    | 7.37      | 0.22   |
|              | 17.16 | 8.82      | 0.24      | 0.03   | 8.75     | 0.21      | 0.02   |
|              | 06.35 | 4.19      | 0.09      | 0.02   | 3.46     | 0.08      | 0.02   |
|              | 07.13 | 10.65     | 0.69      | 0.06   | 10.19    | 0.59      | 0.06   |
|              | 08.21 | 29.57     | 21.70     | 0.73   | 28.56    | 19.80     | 0.69   |
|              | 09.05 | 53.02     | 36.93     | 0.70   | 52.05    | 35.07     | 0.67   |
|              | 09.27 | 53.85     | 16.86     | 0.31   | 53.47    | 14.92     | 0.28   |
|              | 10.11 | 31.99     | 34.51     | 1.08   | 31.24    | 32.78     | 1.05   |
| August 16, 2018 | 11.27 | 113.67    | 39.29     | 0.35   | 111.97   | 38.38     | 0.34   |
|              | 12.14 | 118.16    | 36.88     | 0.31   | 115.87   | 35.99     | 0.31   |
|              | 13.03 | 115.23    | 36.41     | 0.32   | 113.30   | 35.55     | 0.31   |
|              | 14.16 | 102.23    | 37.96     | 0.37   | 99.09    | 36.59     | 0.37   |
|              | 15.19 | 80.62     | 35.61     | 0.44   | 77.03    | 33.87     | 0.44   |
|              | 16.08 | 50.22     | 14.06     | 0.28   | 47.53    | 11.74     | 0.25   |
|              | 17.06 | 26.01     | 9.24      | 0.36   | 24.40    | 7.59      | 0.31   |
Even though previous researches show no significant effect of salt-induced environment on the physical of PV modules, however, the accumulated salt crystals on the surface of the PV module affect the output and efficiency. This effect is due to the full and partial shading caused by the salt accumulation. In the long term of exposition, this condition can reduce significant power output and efficiency. The good thing is the careful maintenance and cleaning of the PV module will return to its initial performance [23].

4. Conclusion
This paper presented the effect of sea salt on PV module output and efficiency by comparing two modules, one installed in normal condition and the other one was doused with sea salt water for every hour from 07.00 AM to 04.00 PM in 16 days. The output measurement results show there were significant differences in production and efficiency. The average output power difference between the normal condition and salt doused PV module in three days is 1.3778 Watt, and the efficiency difference is 0.948. This number is a significant number considering the measurement tests were only taken for three days. The difference gap can be higher by longer time exposed to salt-containing environments. The good thing is with the careful maintenance and cleaning of the PV module will return to its initial performance

5. References
[1]. Tapparan E M D Indonesian Renewable Energy Policy and Investment Opportunities Directorate General of New, Renewable Energy and Energy Conservation, Ministry of Energy and Mineral Resources
[2]. Zed F Integrating Energy Efficiency and Renewable Energy: Least-cost Solution for a Clean Energy Future Directorate General of New, Renewable Energy and Energy Conservation, Ministry of Energy and Mineral Resources
[3]. Yudha H M, Dewi T, Risma P and Oktarina Y 2018 Life Cycle Analysis for the Feasibility of Photovoltaic System Application in Indonesia presented in the IOP Conference Series: Earth and Environmental Science vol 124 p 012005
[4]. Muscat M 2014 A study of floating PV module efficiency Master’s Thesis The University of Malta
[5]. Durkovic V and Durišić Z 2017 Analysis of the Potential for Use of Floating PV Power Plant on the Skadar Lake for Electricity Supply of Aluminum Plant in Montenegro Energies vol 10 p 23 doi:10.3390/en10101505
[6]. Liu L, Wang Q, Lin H, Li H, Sun Q, and Wennersten R 2016 Power Generation Efficiency and Prospects of Floating Photovoltaic Systems presented in The 8th International Conference on Applied Energy – ICAE2016 Engineering Procedia vol 105 p 1136-1142
[7]. Dubey S, Sarvaiya JN, and Seshadri B 2013 Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world - A review. Energy Procedia vol 33 p 311–321
[8]. Dolara A, Lazaroiu GC, Leva S, and Manzolini G 2013 Experimental investigation of partial shading scenarios on PV (photovoltaic) modules Energy vol 55 p 466–475
[9]. Salem F and Awadallah MA. Detection and assessment of partial shading in photovoltaic arrays 2016 Journal of Electrical Systems and Information Technology vol 3 issue (1) p 23–32
[10]. Mahammed IH, Arab AH, Berrah S, Bakelli Y, Khennene M, Oudjana SH, et al 2017 Outdoor study of partial shading effects on different PV modules technologies. Energy Procedia vol 141 p 81–85
[11]. Menoufi K, Farghal HFM, Farghali AA, and Khedr MH 2017 Dust accumulation on photovoltaic panels: A case study at the East Bank of the Nile (Beni-Suef, Egypt) Energy Procedia vol 128 p 24–31
[12]. Wang P, Xie J, Ni L, Wan L, Ou K, Zheng L, et al 2018 Reducing the effect of dust deposition on the generating efficiency of solar PV modules by super-hydrophobic films Solar Energy vol 169 issue (April 2017) p 277–283

[13]. Olivares D, Ferrada P, Matos C De, Marzo A, Cabrera E, Portillo C, et al 2017 Characterization of soiling on PV modules in the Atacama Desert Energy Procedia vol 124 p 547–553

[14]. Dechthummarong C., Wiengmoon B., Chenvidhya D., Jivacate C., and Kirtikara K. 2010 Physical Deterioration of Encapsulation and Electrical Insulation Properties of PV Modules after Long-term Operation in Thailand, Solar Energy Materials & Solar Cells vol 94 p1437-1440

[15]. Mathiak G, Althaus J, Menzler S, Lichtschlaeger L and Herrmann W 2012 PV Module Corrosion by Ammonia and Salt Mist Experimental Study with Full-Size Modules European Photovoltaics Solar Energy Conference and Exhibition Proceedings

[16]. Schinkoethe P, Nieland S, Michael J, Kugler M 2010 PV Modules and Components Under Extraordinary Environmental Conditions Using The Examples of Sodium Chloride Atmospheres 26th European Photovoltaic Solar Energy Conference and Exhibition.

[17]. Walsh T M, Xiong Z, Khoo Y S, Tay A A O, Aberle A G 2011 Singapore Modules – Optimised PV Modules for the Tropics ICMAT Symposium O, Energy Procedia (2011)

[18]. Wang Q, Rui C, Sun J, Zhao X, and Cai J 2013 How to Design Solar Module In the Tropics 28th European Photovoltaics Solar Energy Conference and Exhibition p 3362 – 3364

[19]. Fabero F 2007 CIEMAT: Salt Mist Corrosion Testing of Photovoltaic Modules IEC/TC82/WG2 Meeting

[20]. Illya G, Handara V, Siahandan M, Nathania A, and Budiman A S 2017 Mechanical Studies of Solar Photovoltaics (PV) Backsheets Under Salt Damp Heat Environments 9th International Conference on Materials for Advanced Technologies (ICMAT 2017) Procedia Engineering vol 215 p 238-245

[21]. Sika 2016 Solar Solutions New Horizons in Sealing and Bonding for Photovoltaics Building Trust Switzerland, @SIKA SERVICES AG / SOLAR SOLUTIONS / NEW HORIZONS IN SEALING AND BONDING FOR THE PHOTOVOLTAIC INDUSTRY / CMDL / 04.2015 / ID:55177

[22]. Jäger K, Isabella O, Smets A H M, van Swaaij R A.C.M.M, and Zeman M 2014 Solar Energy: Fundamentals, Technology, and Systems, Delft University of Technology

[23]. Dewi T, Risma P, Oktarina Y, Roseno M T, Yudha H M, Handayani AS, Wijanarko Y 2016 A Survey on Solar Cell; The Role of Solar Cell in Robotics and Robotics Application in Solar Cell Industry in Proc Forum in Research, Science, and Technology, FIRST 2016 pp C19-C22.

[24] R Ploetz, R Rusdiansari and E Eviliiana 2016 Renewable Energy: Advantages and Disadvantages Proceedings Forum in Research, Science, Technology (FIRST)