A preliminary study of common defects of photovoltaic modules in West Timor, Indonesia

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Abstract. Photovoltaic (PV) modules deployed outdoor are exposed to various environmental conditions which can contribute to degrade their power output. Visual inspection is well known as an initial method commonly applied to assess degradation modes of PV modules. By applying the method, it was found that the modules installed on eight off-grid solar power systems in West Timor, Indonesia experienced several degradation modes such as delamination, discoloration, snail trails, microcracks, corrosion, and soiling. These types of degradation are likely attributed to the high temperature, humidity, and salinity level in the region. The degraded panels are still operating to provide electricity for the community in these areas. However, it can be predicted that the energy produced is not optimal as healthy PV modules. Further research needs to be carried out to assess relationship of the degradation modes and their effect to the value of electrical parameters of the modules.

1. Introduction

The usage of photovoltaic (PV) module for generating electricity in many areas has shown a distinct rapid progress in recent years [1]. PV module classified as an active solar technology shares high reliability, no requirement for additional resource, and low maintenance cost [2]. In addition to the advantage factors, the number of PV panel’s application is predicted to increase in the future as the rapid decreasing of the system’s cost [1].

One of the potential factors to reduce the power produced by the PV module is shading that can be caused by dust and high objects around the PV module area such as buildings and trees [3-5]. Shading reduces the amount of sunlight to reach the cells of the modules. As a result, the energy yielded by solar panels decreases. Performance degradation caused by shading is temporary and can be addressed, for example, by planning proper installation and routine maintenance [6-8].

Performance of PV module quantified by its power output can also decrease permanently due to the system’s exposure to the various environmental factors such as chemical elements, temperature, and humidity [9]. PV module experiencing permanent degradation introduced some signs such as moisture ingress, changes in colour, loss of adhesion, and cracks [10].

There have been many studies conducted to identify degradation modes of PV modules. Sharma and Chandel [10] investigated the degradation of polycrystalline silicon (pc-si) modules installed in Hamirpur, India. They reported that the modules which had been installed for 2.5 years exhibited snail trails, junction box failure, and discoloration. Power output of the modules accounting serious defects decreased up to 50%, while 0.6-2.5% degradation was recorded from minor defects’ modules. Djorjevic et al [11] in a work revealed that modules installed in Western Australia suffered from all modes of degradation such as corrosion on junction boxes, discoloration, soiling, glass breakages, and delamination. The study also found that snail trails appeared in the modules even after 3-5 months exposure in the field.
Like other systems in the world, PV panels deployed on off-grid systems in West Timor, Indonesia also experienced permanent performance degradation. A research performed by Tanesab et al [12] at a location in West Timor reported that power output of the degraded modules decreased by 2% every year. Visual inspection results showed that corrosion, delamination, and discoloration were noticeable defects found in the examined modules. However, the study only cover done PV system so that it cannot represent the degradation modes of modules in West Timor. This was a follow-up study carried out at several off-grid solar power projects across East Timor region. Visual inspection method referring to the standard inspection published by the International Energy Agency was applied to assess the degradation of the modules [13].

West Timor exhibits a long dry season (around 8 months) and high humidity (70-90%) [14]. In addition, the island is located near the sea so that modules installed in the region are exposed to high levels of salinity and ionic contaminations. These conditions, understandable, would have different effects on PV module degradation modes. This study is expected to complement the literature on the investigation of solar module degradation modes, especially in tropical regions which is difficult to find.

2. Experimental procedure
PV modules deployed on eight off-grid PV systems in several areas in West Timor were observed visually. The systems are located at Politeknik Negeri Kupang/PNK, Erbaun village, Nunkolo village, Lotas village, Dubesi village, Manumutin village, and Fatulotu village. Location of the systems is depicted in figure 1. Except for the PNK system (2007), the other systems were built in between 2011 and 2013. Layout of the off-grid PV systems are shown in figure 2.

Considering the irradiance suggested by the International Electrotechnical Commission (IEC) is above 1000 W/m² [15], the inspections were carried out on sunny days. It was expected that the modules were exposed to enough sunlight. The reflection process was avoided because it could result in defective images. In addition, the inspection procedures were also done from different angles to avoid error assessments [9]. As mentioned in the previous section, observations were performed to detect the defects on cells, frames, junction boxes, and wiring of the modules. Defects refer to conditions where parts of the modules are not as expected or differ from normal conditions.

![Figure 1. Map of Indonesia [16], West Timor [17] and locations of the investigated PV systems](image-url)
Figure 2. Common configuration of off-grid solar power systems in West Timor

3. Results and discussion

Based on the visual inspection, it was found that the PV modules in West Timor experiencing some defect types such as discoloration, snail tracks, glass breakages, corrosion, failure on junction box, delamination, and soiling.

3.1. Discolouration

Visual inspection results showed that discoloration appeared on all examined PV systems. Complete colour change of entire cells was noticed on a group of monocrystalline PV modules installed at PNK (figure 3). Shading from trees around the PV area, soiling, and bird droppings (figure 4) contributed to the severity of discoloration experienced by these modules [9]. It can be predicted that the degradation mode degraded the performance of PV modules in West Timor as it reduced the intensity of sunlight to reach the cells of the modules. Energy produced by the panels can be recovered by applying a cleaning procedure. Literature revealed that discoloration could be sparked by internal factors namely (poor quality of encapsulants) and external factors (changes in temperature and humidity) [10].

Figure 3. Discoloration of PV modules at PNK
3.2. Snail trails
The study results showed that snail trails mode was found on several PV modules in all PV systems. Snail trails are caused by the formation of silver acetate that is synthesized by etilena vinil asetat (EVA) encapsulation and silver pastes (silver carbonate/Ag₂CO₃). The number of affected cell and module at PNK which has been operating for almost 17 years was higher than the others. It was found that, on an average, only two to four cells of a module exhibited snail trails degradation. An image of snail trails of monocrystalline PV modules installed at Erbaun PV system is shown in figure 5. This result is not surprising because in several studies [9-11] reported that snail trails appeared on modules only after few months of commissioning. Nevertheless, the degradation mode growing on the cells are very slow. This type of degradation is the forerunner to cracks in cells [10].

3.3. Glass breakages
Glass breakages is a mode of degradation that can be observed with the naked eye. Modules with broken glass can still operate normally, but this can cause moisture infiltration and electric shock. Cracks on PV cover’s glass reduce power output and also accelerate further degradation modes such as corrosion, delamination and discoloration. Glass breakages can occur due to mishandling during installation, maintenance, and transportation. Figure 6a shows an image of a glass breakage monocrystalline PV module found at Nunkolo PV system. Considering the location of the PV system is hilly and only can be accessed using 4WD, it is suspected that the major contribution factor is due...
to poor handling when transporting. The same degradation was also noticed on a monocrystalline PV module at Dubesi system (figure 6b). Based on its pattern, it can be confirmed that the breakage was a result of an act of vandalism.

![Microcracks of a PV module at Nunkolo(a) and Dubesi (b)](image)

3.4. Failure on junction box

Junction box is a hub to connect several PV modules into strings. The box is placed on the back of a solar panel. Results of the visual inspection revealed that the junction boxes of some PV modules inspected in West Timor were not tightly closed. As a consequence, corrosion was found in the PVs’ electrical terminals. A picture of the phenomenon is shown in figure 7a. This degradation was only found at PNK system. In addition to the old enclosure materials of the junction boxes, location of the system is close to the sea so that the modules were exposed to high level of salinity which accelerate the corrosion. Beside corrosion, adhesion loss of junction box of a monocrystalline PV module was found at Babuin system (figure 7b). Mishandling during installation or maintenance was likely the major factors contributing to the failure.

![Corrosion and loss of adhesion of junction box of PV modules at PNK (a) and Babuin (b), respectively](image)

3.5. Encapsulant delamination

Encapsulant delamination is one of the degradation modes often found in PV modules. The degradation is characterized by encapsulants between the front surface of the solar cell and the glass cover [9]. The encapsulant material, usually ethylene vinyl acetate (EVA), is processed at a specified
temperature and time during lamination. Inexpensive materials or incorrect processing results in discoloration or delamination. Encapsulation should be tested for moisture, resistivity, adhesion, UV exposure, water intake, etc. [18]. Delamination was experienced by several modules in all investigated PV systems. Modules at PNK system accounted more delamination compared to the other systems. This is attributed to the older age of the system. Photograph of encapsulant delamination of a module installed at Manumutin system is depicted in figure 8.

![Figure 8. Encapsulant delamination of a module at Manumutin](image)

3.6. Soiling
Solar PV panels deployed in the field are exposed to various environmental conditions that can reduced their energy production. Soiling is one of the inevitable detrimental factors which degrade PV performance significantly. Inspection results revealed that the PV modules deployed at all systems experienced the same situation. Figure 9a shows the modules at PNK that have not yet been cleaned for about 8 months after the rainy season. The amount of dust that attach on the modules’ surfaces among the systems is different [19]. As mentioned previously, soiling accumulation is influenced by environmental conditions around the PV system. Larger amount of soiling on the modules’ surfaces at PNK higher than the other system, for example Dubesi system (figure 9b). It was a consequence of high activities of vehicles and human around the PV area. Soiling degradation moderuces the electric power generated by the modulesthat lead to economic losses [5,20].

![Figure 9. Soiling degradation of PV modules at PNK (a) and Fatulotu (b)](image)
Table 1: Summary of degradation modes of the investigated PV modules in West Timor

| PV locations | PV technologies         | Degradation modes                  |
|--------------|-------------------------|------------------------------------|
| PNK          | Monocrystalline         | Discoloration                      |
|              |                         | Snail trails                        |
|              |                         | Delamination                        |
|              |                         | Soiling                             |
|              |                         | Corrosion                           |
| Erbaun       | Monocrystalline         | Discoloration                      |
|              |                         | Snail trails                        |
|              |                         | Delamination                        |
|              |                         | Soiling                             |
| Babuin       | Monocrystalline and     | Discoloration                      |
|              | polycrystalline         | Snail trails                        |
|              |                         | Delamination                        |
|              |                         | Soiling                             |
|              |                         | Failure on junction box             |
| Nunkolo      | Monocrystalline         | Discoloration                      |
|              |                         | Snail trails                        |
|              |                         | Delamination                        |
|              |                         | Soiling                             |
|              |                         | Glass breakage                      |
| Lotas        | Monocrystalline         | Discoloration                      |
|              |                         | Snail trails                        |
|              |                         | Delamination                        |
|              |                         | Soiling                             |
| Dubesi       | Polycrystalline         | Discoloration                      |
|              |                         | Snail trails                        |
|              |                         | Delamination                        |
|              |                         | Soiling                             |
|              |                         | Glass breakage                      |
| Manumutin    | Monocrystalline         | Discoloration                      |
|              |                         | Delamination                        |
|              |                         | Snail trails                        |
|              |                         | Soiling                             |
| Fatulotu     | Monocrystalline         | Discoloration                      |
|              |                         | Snail trails                        |
|              |                         | Delamination                        |
|              |                         | Soiling                             |

Based on the observations’ results, it can be seen that discoloration, snail trails, delamination, and soiling are the degradation modes exhibited by PV modules in all research sites. Corrosion, glass breakage, and failure of junction box were only found in some sites. These results are summarized and depicted in table 1.

The degraded PV modules are still operating to provide electricity for the community in these areas. However, it can be predicted that the energy produced is not optimal as healthy PV modules. Further research needs to be carried out to assess relationship of the degradation modes and their effect to the value of electrical parameters of the modules.

4. Conclusion
This study aimed to investigate degradation modes of PV modules deployed at eight off-grid PV systems in West Timor, Indonesia. Visual inspection results revealed that the modules introduced several types of degradation such as corrosion on junction boxes, discoloration, microcracks, encapsulant delamination, snail trails, and soiling. Humidity, temperature, and chemical materials are likely the natural factors contributed to the degradation modes. PV module at PNK system exhibited more degradation modes than other investigated systems. The age of the module and environmental factors such as high humidity and temperature, high level of salinity were the factors responsible for the degradation. The effect of the degradation caused by soiling can be addressed by performing a cleaning procedure. Further research needs to be carried out to assess relationship of the degradation modes and their effect to the value of electrical parameters of the modules.
5. References

[1] IEA. PVPS Trends 2016 In Photovoltaic Applications. 2016 [cited 2018 2 Agustus]; Available from: http://iea-pvps.org/index.php?id=256.

[2] IEA, Technology Roadmap; Solar Photovoltaic Energy. 2009.

[3] Tanesab, J., Parlevliet, D., Whale, J., Urmee, T., & Pryor, T. (2015). The contribution of dust to performance degradation of PV modules in a temperate climate zone. Solar Energy, 120, 147-157. doi: http://dx.doi.org/10.1016/j.solener.2015.06.052

[4] Tanesab, J., Markus, D. L., Ambrosius, A. T., & Yohanes, S. P. (2018). Experimental study of dust impact on power output degradation of various photovoltaic technologies deployed in West Timor, Indonesia. IOP Conference Series: Earth and Environmental Science, 188(1), 012038.

[5] Tanesab, J., Parlevliet, D., Whale, J., & Urmee, T. (2018). Energy and economic losses caused by dust on residential photovoltaic (PV) systems deployed in different climate areas. Renewable Energy, 120, 401-412. doi: https://doi.org/10.1016/j.renene.2017.12.076

[6] Martínez-Moreno, F., J. Muñoz, and E. Lorenzo, Experimental model to estimate shading losses on PV arrays. Solar Energy Materials and Solar Cells, 2010. 94(12): p. 2298-2303.

[7] Dolara, A., et al., Experimental investigation of partial shading scenarios on PV (photovoltaic) modules. Energy, 2013. 55(0): p. 466-475.

[8] Sathyanarayana, P., et al., Effect of shading on the performance of solar PV panel. Energy and Power, 2015. 5(1A): p. 1-4.

[9] Kumar, M. and A. Kumar, Performance assessment and degradation analysis of solar photovoltaic technologies: A review. Renewable and Sustainable Energy Reviews, 2017. 78: p. 554-587.

[10] Sharma, V. and S. Chandel, A novel study for determining early life degradation of multicrystalline-silicon photovoltaic modules observed in western Himalayan Indian climatic conditions. Solar energy, 2016. 134: p. 32-44.

[11] Djordjevic, S., D. Parlevliet, and P. Jennings, Detectable faults on recently installed solar modules in Western Australia. Renewable Energy, 2014. 67: p. 215-221.

[12] Tanesab, J., Parlevliet, D., Whale, J., & Urmee, T. (2017). Seasonal effect of dust on the degradation of PV modules performance deployed in different climate areas. Renewable Energy, 111, 105-115. doi: https://doi.org/10.1016/j.renene.2017.03.091

[13] Köntges, M., Kurtz, S., Packard, C., Jahn, U., Berger, K., Kato, K., . . . Iseghem, M. V. (2014). Review of Failures of Photovoltaic Modules Report IEA-PVPS T13-01: 2014. International Energy Agency-Photovoltaic Power Systems Programme.

[14] Bureau of Meteorology, Climatological and Geophysics of Kupang. Data Klimatologi Bulanan Tahun 2014 dan 2015 (Monthly Climatological Data Year 2014 and 2015). 2015.

[15] IEC-Standard-60891. (2009). International Electrotechnical Commission.

[16] http://tanahair.indonesia.go.id/portal-web

[17] https://id.m.wikipedia.org/wiki/Berkas:East_Timor_map_mhn.jpg

[18] Quintana, M.A., et al. Commonly observed degradation in field-aged photovoltaic modules. in Photovoltaic Specialists Conference, 2002. Conference Record of the Twenty-Ninth IEEE. 2002.

[19] Tanesab, J., Parlevliet, D., Whale, J., & Urmee, T. (2019). The effect of dust with different morphologies on the performance degradation of photovoltaic modules. Sustainable Energy Technologies and Assessments, 31, 347-354.

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