# Special Performance Evaluation of Photo Voltaic Power Plant in Gili Trawangan Solar Power Plant to Achieve Photovoltaic Reliability Excellence

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**PLN committed to achieve New and Renewable Energy (NRE) mixture up to 23% in 2025 that consists of 8.0% water, 7.3% geothermal, 1.8% wind & solar, and 5.8% biomass/waste/co-firing as listed in the 2021-2030 Electricity Procurement Plan (RUPTL) of PLN, as the greenest or environmentally friendly RUPTL with the portion of NRE power plants set to 51.6%. To achieve such ambitious target, PLN has developed several Communal Photovoltaic Power Plants either Off-Grid System, On-Grid System and also Hybrid System, scattered across Indonesia especially in the small and remote island in the eastern region of Indonesia. This paper aims to give insight of performance evaluation through special maintenance program like PV Panel Scanning and Mapping to main component of Photovoltaic (PV) Power Plant, especially in the West Nusa Tenggara Region. The scope of performance evaluation focused on main component of PV Power Plant like PV (Photo Voltaic) panel, and inverter only. Content of the paper includes lesson-learned and success story of PV Power Plant operation and maintenance.**

**Keywords— Performance Evaluation, Special Maintenance, Photo Voltaic (PV), Panel Scanning and Mapping, Lesson Learned.**

## Introduction

Solar energy is converted into usable electricity by photovoltaic panel. Due to its abundance, quiet operation, and favorable environmental impact, solar energy has grown more significant. Moreover, the modularity, dependability, and lower maintenance costs of the PV solar plants could give more benefits from solar energy. They perform well for standalone applications due to less expensive to implement compared to the standard ones.

PV plant's primary function is to turn light into electricity. The photoelectric effect is used in this conversion, where it basically consist of [1]:

- PV generators,
- The mounting system,
- The Inverters,
- The connection cables,
- Electrical connections,
- The voltage measurement equipment,
- The energy meters.

Recently, distributed PV power plants, especially those in rural areas, operate unmanaged. Some irregularities have performed unnoticed despite investigations and fixed by the staff in charge of these plants' monitoring. Additionally, there may not be enough time to correct these mistakes, which could have disastrous consequences for the system.

Early detection and diagnosis of problems and their implications is made possible by the Special Maintenance technique known as Reliability Centered Maintenance (RCM) [3], this method adopted in this paper through PV Array and Module Failure Mapping. RCM is applied to provide preventive maintenance, real-time monitoring, predictive maintenance, and proactive maintenance approaches in an integrated manner [5].

The PV power plant at Gili Trawangan is designed as a microgrid system. This paper also is intended to assess an early fault and perform special maintenance procedures on the Gili Trawangan PV Power Plant.

From the PV Module data obtained, Inverter G1 uses the Polycrystalline type while Inverters G2 and G3 use the Monocrystalline type. The detail specification of PV Module and also the number of PV modules installed at Gili Trawangan can be exercised as shown in Table I and Table II, respectively.

Table I. PV Module specification of Trawangan Solar Power Plant

| PV MODULE SPECIFICATION | GILI TERAWANGAN SOLAR POWER PLANT | | | | | |
|---|---|---|---|---|---|---|
| | G1 | | | | G2 | G3 |
| Brand | SUNTECH | SKYTECH | LEN | SOLPOWER | LEN | LEN |
| Output Power (Pmax) | 220 | 220 | 245 | 220 | 180 | 180 |
| Maximum Power Voltage (Vpm) | 29,5 | 29,82 | 29,88 | 30 | 35,6 | 35,6 |
| Maximum Power Current (Ipm) | 7,46 | 7,39 | 8,2 | 7,35 | 5,06 | 5,06 |
| Open Circuit Voltage (Voc) | 36,6 | 36,24 | 37,34 | 36,2 | 44,1 | 44,1 |
| Short Circuit Current (Isc) | 8,05 | 7,93 | 8,63 | 7,95 | 5,52 | 5,52 |
| Efficiency | | | | | 14 - 15 | 14 - 15 |

Table II. Number of modules of Gili Trawangan Solar Power Plant

| UNIT | INVERTER | Number of PV | COMBINER | Number of String | Number PV per String | Total number of PV | Nominal Voltage |
|---|---|---|---|---|---|---|---|
| GILI TERAWANGAN SOLAR POWER PLANT | G1 | 920 | G1 COMBINER 1 | 12 | 20 | 240 | 590,0 |
| | | | G1 COMBINER 2 | 12 | 20 | 240 | 590,0 |
| | | | G1 COMBINER 3 | 12 | 20 | 240 | 590,0 |
| | | | G1 COMBINER 4 | 10 | 20 | 200 | 590,0 |
| | G2 | 1120 | G2 COMBINER 1 | 14 | 16 | 224 | 569,6 |
| | | | G2 COMBINER 2 | 14 | 16 | 224 | 569,6 |
| | | | G2 COMBINER 3 | 14 | 16 | 224 | 569,6 |
| | | | G2 COMBINER 4 | 14 | 16 | 224 | 569,6 |
| | | | G2 COMBINER 5 | 14 | 16 | 224 | 569,6 |
| | G3 | 1120 | G3 COMBINER 6 | 14 | 16 | 224 | 569,6 |
| | | | G3 COMBINER 7 | 14 | 16 | 224 | 569,6 |
| | | | G3 COMBINER 8 | 14 | 16 | 224 | 569,6 |
| | | | G3 COMBINER 9 | 14 | 16 | 224 | 569,6 |
| | | | G3 COMBINER 10 | 14 | 16 | 224 | 569,6 |

## Metodology of Research

The data taken as evaluation material both related to parameters and physical conditions of the Solar Power Plant installation (PV Module, string box, combiner box, and inverter) which is carried out at the same time frame between 10.30 a.m to 2.30 p.m. The data collection points can be described according to the following layout:

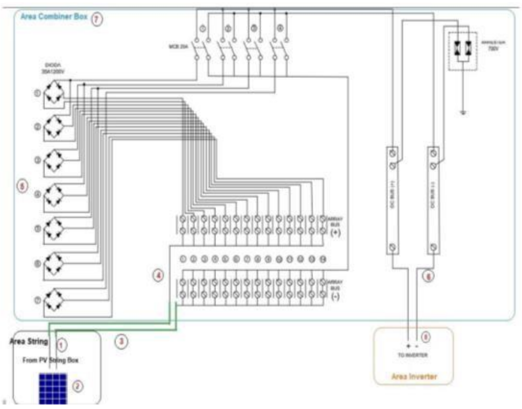


Fig. I. Schematic Diagram to collect Data from Gili Trawangan Solar Power Plant

Identification of PV module deterioration has turned into an essential tool to evaluate and identify the health of PV modules. Real-time exposures are required to verify the module degradation. The little moisture that enters is pushed out daily as the module's temperature rises. The slow degradation of the encapsulant material by the ultraviolet light causes it to lose some of its elastic properties. As time passes, it becomes impossible to push out the moisture. Resistance rises caused by corrosion is triggered by internal moisture in the cell and reduces the module's operational voltage. [2]

The percentage of PV module critical component failure are shown in table III [1].

Table III. Percentage of PV Module critical component failure [1]

| PV Module parts | 1st year degradation | Degradation Between 1st and 3rd year | Degradation after 3rd year |
|---|---|---|---|
| PV Panels | 25% | 15% | 15% |
| Mounting Structure | 3% | 1% | 1% |
| Cables, Protection, electrical connection | 10% | 20% | 30% |
| Inverters | 55% | 60% | 50% |
| Less voltage equipment | 5% | 3% | 3% |
| Energy meters | 2% | 1% | 1% |

From Table III above, PV Panels are one of PV Module parts that degrades early than other parts. The common failure modes of PV faults include short time open circuit fault, long time open circuit fault, short circuit fault, partial shading fault, periodic shading fault, permanent shading fault, and degradation fault [4].

## Result

### PV Array and Module Failure Mapping

PV modules assess one by one to ensure that there are no broken solar modules, damaged lamination (air bubbles), discolored cells, snail tracks, short circuits. The result of PV Solar Module Failure Mapping especially for G2 and G3 Inverter of Gili Trawangan Solar PV can be shown in Fig. 2.


Fig. 2. PV Array and Module Failure Mapping of Gili Trawangan PV Power Plant

The recap of PV module condition assessment connected to G2 inverter and G3 inverter can be shown in table IV and table V below.

Table IV. Recap of PV Module condition assessment connected to G2 inverter

| G2 Data | Number | Percentage |
|---|---|---|
| NORMAL | 125 | 11% |
| OXIDATION | 736 | 66% |
| CRACKING | 24 | 2% |
| BREAKDOWN | 203 | 18% |
| NEW PV PANELS (JULY 2018) | 32 | 3% |
| NEW PV PANELS (JANUARY 2021) | 0 | 0% |
| NEW PV PANELS (JANUARY 2022) | 0 | 0% |
| BREAKDOWN PV PANEL THAT HAD BEEN REPAIRED | 0 | 0% |
| CRACKING PV PANELS THAT HAD BEEN REPLACED | 0 | 0% |
| **Total** | **1120** | **100%** |

Table V. Recap of PV Module condition assessment connected to G3 inverter

| G3 Data | Number | Percentage |
|---|---|---|
| NORMAL | 140 | 13% |
| OXIDATION | 430 | 38% |
| CRACKING | 5 | 0% |
| BREAKDOWN | 47 | 4% |
| NEW PV PANELS (JULY 2018) | 48 | 4% |
| NEW PV PANELS (JANUARY 2021) | 100 | 9% |
| NEW PV PANELS (JANUARY 2022) | 300 | 27% |
| BREAKDOWN PV PANEL THAT HAD BEEN REPAIRED | 35 | 3% |
| CRACKING PV PANELS THAT HAD BEEN REPLACED | 15 | 1% |
| **Total** | **1120** | **100%** |

Choosing the right type of PV Module will determine the maximum results according to the climate or weather that is appropriate in the area. Apart from the price of the PV Module, in the Gili Trawangan Solar Power Plant, from the history of production achievements, the G1 inverter, which uses the Polycrystalline type, is still far superior and reliable compared to the G2 & G3 inverters, which use a monocrystalline type. The production performance of the last three years shows that on inverter G1 reached 44% compared to achievements on inverters G2 & G3, which reached 29% and 28% respectively. Based on the actual data in the field in terms of production achievement and physical conditions, the Polycrystalline PV Module is more reliable than the Monocrystalline type for the Gili Trawangan location.

Almost 50% out of 3,160 PV Modules, are experienced problems such as Oxidation (37%), Cracking (1%) & Breakdown (8%). Based on data, the 3 inverters that experienced the most problems (damaged) were inverter G2 followed by inverter G3. The large number of damaged PV modules is taken into consideration for taking proper maintenance actions and even planning to replace PV Modules accordingly to increase the penetration of solar energy.

Gili Trawangan Solar Power Plant's monthly kWh production on the G1 inverter is outperformed the G2 & G3 inverters. The trend of decreasing production of the Gili Trawangan Solar Power Plant from year to year is required to be studied and analyzed of its material. Besides that, the difference production between G1 and G2 & G3 is also required to be analyzed both in terms of the condition & type of PV installed and its impact on reliability of the PV. The comparison of monthly kWh production between inverter G1, G2, and G3 is shown as picture in the Fig. 3 below.

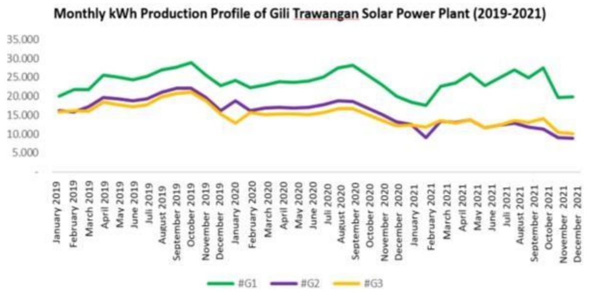


Fig. 3. Monthly kWh Production Profile of Gili Trawangan Solar Power Plant (2019-2021)

**Data Analysis**

Hasil kerja juga didukung dan diperkuat oleh literatur-literatur yang tepat dan akurat. Bagian ini juga menjelaskan urgensi dari proyek ini dan kemanfaatan terutama berkaitan dengan profesi sebagai seorang insinyur. Hasil kerja ditulis tidak lebih dari 1500 kata.

An analysis is carried out by comparing the values of voltage and current between the string and combiner outputs as well as evaluating the physical condition of each PV module. The voltage and current data for each string and combiner are accumulated and then analyzed in comparison between the actual output value for each combiner with the maximum voltage (Vpm) and maximum current (Ipm) values according to the data on the name plate as well as an analysis of the actual physical condition of the PV Module in field. The relationship between Vpm and Ipm as well as Voc (open circuit voltage) and Isc (short circuit current) of a PV Module can be illustrated via the following graph:

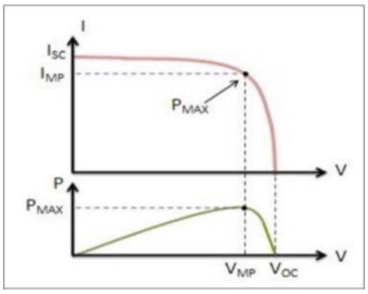


Fig. 4. The relationship between Current Curve I and Voltage V with Power P on a PV Module

The maximum power (Pmax) on the I-V curve is the operating point which shows the maximum power resulting from the meeting of Imp and Vmp produced by the PV Module, so it can be formulated as follows:

P_max=V_oc.I_sc.FF……………………(1)

where:

Voc= Maximum voltage capacity that can be achieved when there is no current (Isc=0)

Isc= Maximum output current from the PV Module with no resistance conditions or assuming a short circuit so that the voltage becomes zero (Voc=0)

FF= Fiil Factor value which usually ranges from 0.7 to 0.85.

Fiil Factor defined as follows:

FF = (V_mp.I_mp)/(V_oc.I_sc ) …………..……………(2)

where:

Vmp= Voltage at maximum power

Imp= Current at maximum power

Voc= Maximum voltage capacity that can be achieved when there is no current (Isc=0)

Isc= Maximum output current from the PV Module with no resistance conditions or assuming a short circuit so that the voltage becomes zero (Voc=0)

FF= Fiil Factor value which usually ranges from 0.7 to 0.85.

The comparison value of the current and voltage of the Combiner G2 and G3 with the standard name plate is illustrated as shown in the Fig. 5 below.

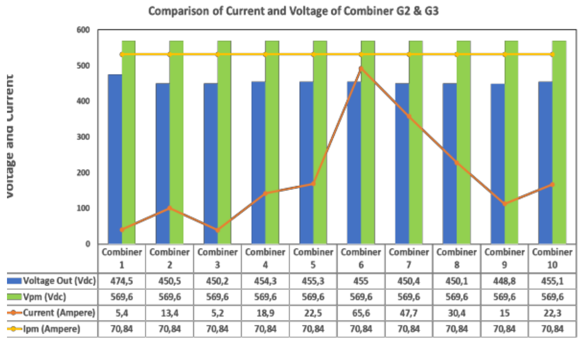


Fig. 5. Comparison of current and voltage of Combiner G2 and G3

If each data on the name plate is assumed to be the maximum value that can be taken as a comparison, then for each string with a current (Ipm) of 5.4A connected in parallel, the maximum output current (Ipm) on the combiner is 70.84A. From the graph above, the actual voltage and current values are still far below the standard maximum current values according to the nameplate, especially the current values that are achieved very low with an average value of 13.08 amperes or 18.46% (inverter G2) and 36.20 amperes or 51.10% (inverter G3). This achievement is very low compared to the maximum current condition (Imp) that should be obtained.

To find out its performance, an analysis of the output current on each string and combiner is carried out to determine the effect on the physical condition of the PV Module. The data that to be compared is data on inverter G2 (combiner 1 to combiner 5) and inverter G3 (combiner 6 to combiner 10) because the inverters G2 & G3 experienced a significant decrease in performance compared to inverter G1. The output current for each combiner is described according to the following graph in Fig. 6:

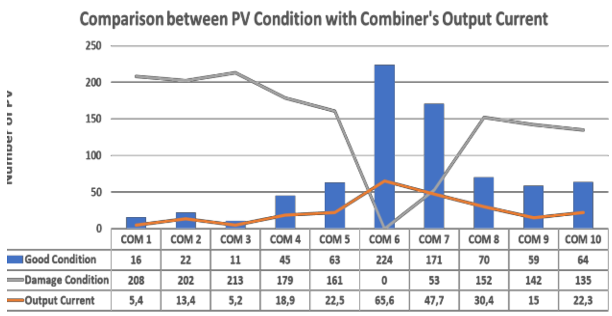


Fig. 6. Comparison between the PV Condition with Combiner’s output current

From the graph above, the output current in the combiner depends on the condition of a PV Module, the more PV Modules with good conditions, the higher the actual output current value and vice versa. The good condition of a PV Module is a condition that is included in the normal category or a condition of new PV without any problems such as cracking, oxidation, breakdown, snail tracks and changes in the surface color of the PV Module.

**Special Maintenance To Improve PV Performance**

Based on the condition and evaluation of the PV Module that experienced reliability decreasing, besides arranging routine preventive maintenance and corrective maintenance on Gili Terawangan Solar Power Plant, a special maintenance is set up to improve its performance. This special maintenance is performed to improve the reliability of the PV Module including:

a. Repairing oxidized buswire soldering by using the appropriate material (tin) to restore the function of the buswire as a conducting medium which previously experienced a short circuit or resistance.

b. Periodic replacement of diode blocking based on current and voltage monitoring on the combiner.

c. Monitoring all the installations from PV Modules to Inverters, both measuring voltage & current and inspecting the physical condition of Solar PV Power Plant components.

The illustration of special maintenance by repairing the oxidized buswire is shown in the Fig. 7 below.


Fig. 7. Special Maintenance by repairing buswire of PV Module

The benefit and effect after repairing buswire PV module can be shown in the following graph. Regardless the changes in weather and ambient temperature, from the graph below, there has been an increase in production after buswire repairs were conducted during the period May 2022 – July 2022 with an average increase of 16% each month.

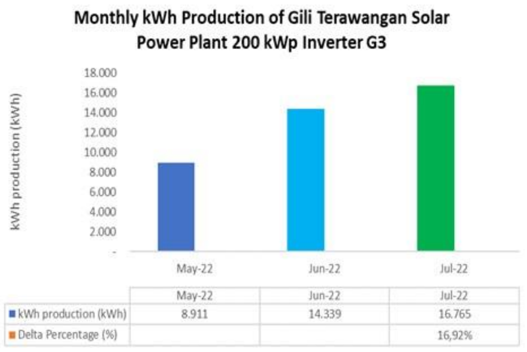


Fig. 8. Comparison kWh Production of Gili Trawangan Solar Power Plant 400 kWP G3 from May 2022 to July 2022

## Evaluation and Conclusion

The declining of Gili Trawangan Solar Power Plant's reliability, resulting decreasing in kWh production of PV module from year to year, approximately from 17% to 19% per year. The performance of kWh production in the last three years of Gili Trawangan Power Plant on inverter G1 reached 44% compared to achievements on inverters G2 & G3, which reached 29% and 28% respectively. Conducting the PV Solar Power Plant special maintenance program using the buswire repair method (May 2022 to July 2022) can improve performance and reliability of the PV Module, with an increase in kWh production of up to 16%.

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