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Improving Grati 1.5 MWp Land-based Bifacial PV Production by Increasing Albedo with White Coral

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Abstrak

Pembangkit Listrik Tenaga Gas dan Uap (PLTGU) Grati saat ini mengoperasikan Pembangkit Listrik Tenaga Surya (PLTS) berbasis darat dengan modul panel surya bifasial berkapasitas 1,5 MWp. Saat ini, radiasi matahari belum dapat diserap secara optimal karena permukaan bawah panel bifasial belum dimanfaatkan. Oleh karena itu, diperlukan suatu material yang berfungsi memantulkan radiasi matahari, sehingga permukaan bawah panel surya bifasial dapat menyerap radiasi tersebut. Dalam hal ini, karang putih dipilih untuk digunakan sebagai reflektor, karena memiliki nilai albedo yang tinggi, mudah diperoleh, dan berbiaya rendah. Penelitian ini bertujuan untuk mengetahui sejauh mana peningkatan kinerja karang putih dalam meningkatkan produksi PLTS berbasis darat Grati. Penelitian ini dilakukan dengan membandingkan karang putih dan albedo tanah melalui studi literatur, survei lapangan, simulasi menggunakan perangkat lunak PVsyst, serta perhitungan persentase peningkatan aktual produksi listrik PLTS. Berdasarkan hasil pengukuran produksi PLTS, penggunaan karang putih sebagai reflektor di bawah panel bifasial dapat meningkatkan produksi listrik sebesar 3,8% dibandingkan dengan albedo tanah.

***Kata kunci**: Bifacial PV, albedo, white coral.*

Abstract

Grati Combined Cycle Power Plant (CCPP) operates a Land-based PV with 1.5 MWp bifacial solar panel modules. Currently, the solar irradiance has not been absorbed optimally yet because the bottom surface of the bifacial has not been utilized. Therefore, it requires a material which functions to reflect the irradiance of the sun so that the bottom surface of the bifacial PV can absorb the irradiance. In this case, the white coral is chosen to apply as a reflector, due to its high albedo value, available and low price. This research aims to see how large the improvement of the white coral in increasing the Grati Land-based PV production. This research is to compare it with soil albedo through a literature study, field survey, PVsyst simulation and the calculation of actual increase percentage in PV production. Based on the measurement of PV production, the usage of white coral as a reflector below the bifacial panel can increase the PV production amounts 3.8% higher than the soil albedo.

***Keywords**: Bifacial PV, albedo, white coral.*

1. INTRODUCTION

Grati Combined Cycle Power Plant (CCPP) is now operating a 1.5 MWp *Land-based* Bifacial PV which is utilized to supply a part of power for the auxiliary equipment, where it was supplied fully by PLN 150 kV grid. The *Land- based* bifacial PV is in 10,712 m² effectively area in Wates Village, Lekok Sub-district, Pasuruan Regency, East Java Province. The following is the location of PV Grati in figure 1.

Figure 1. Grati PV location
(Source: PLN IP Grati)

Grati 1.5 MWp *Land-based* Bifacial PV is developed by considering two reasons. The first is that Grati CCPP location has a higher irradiance than average in Indonesia which is 2,122 kWh/m² per year (GHI), while the second is Grati CCPP still has unutilized land about 6 ha. Based on its operation planning, Grati 1.5 MWp *Land-based* Bifacial PV will generate the electrical energy about 2,283 kWh in a year. The planning is determined by the PVsyst simulation below.

Project: PT IP UP Grati Pasuruan
Variant: New simulation variant1
ATW Solar Indonesia (Indonesia)

PVsyst V7.1.4
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Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	126.0	63.61	27.70	120.7	109.1	147.9	142.2	0.782
February	124.9	82.43	27.45	121.9	110.5	149.4	143.7	0.783
March	145.1	93.58	27.83	145.4	131.9	178.0	171.2	0.782
April	145.8	75.05	28.24	150.7	137.3	183.9	176.7	0.778
May	162.4	69.53	28.64	175.2	159.4	213.4	205.2	0.778
June	159.8	58.43	27.59	176.1	160.1	215.2	207.0	0.780
July	168.5	60.44	27.60	184.1	167.6	224.9	216.2	0.779
August	175.8	74.30	27.59	186.1	170.1	227.9	219.1	0.781
September	174.0	78.81	28.08	177.6	162.4	216.4	208.0	0.777
October	183.5	95.13	29.22	180.8	165.1	219.7	211.2	0.775
November	198.8	85.84	28.83	189.7	173.5	230.9	221.9	0.777
December	143.7	87.37	28.32	136.5	123.6	166.8	160.5	0.780
Year	1908.5	944.51	28.10	1944.7	1770.7	2374.4	2282.8	0.779

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

Figure 2. Properties of Grati 1.5 MWp Land-based Bifacial PV location
(Source: PVsyst, PLN IP PV project)

Grati 1.5 MWp *Land-based* Bifacial PV configuration consists of 2816 bifacial modules, 12 inverters with 1200 kW capacity. Inverter no. 1 to 11 have 10 MPPTs connected to 10 PV strings. Each PV string/MPPT consists of 24 pieces of 535 Wp PV modules connected in series. Each inverter no. 1 to 11 with 10 MPPT has a total module capacity of 128.4 kWp. Inverter no. 12 has 88.16 kWp total module

capacity. All the modules output is connected to the 6.3 kV bus. The Grati PV placement configuration is as follows.

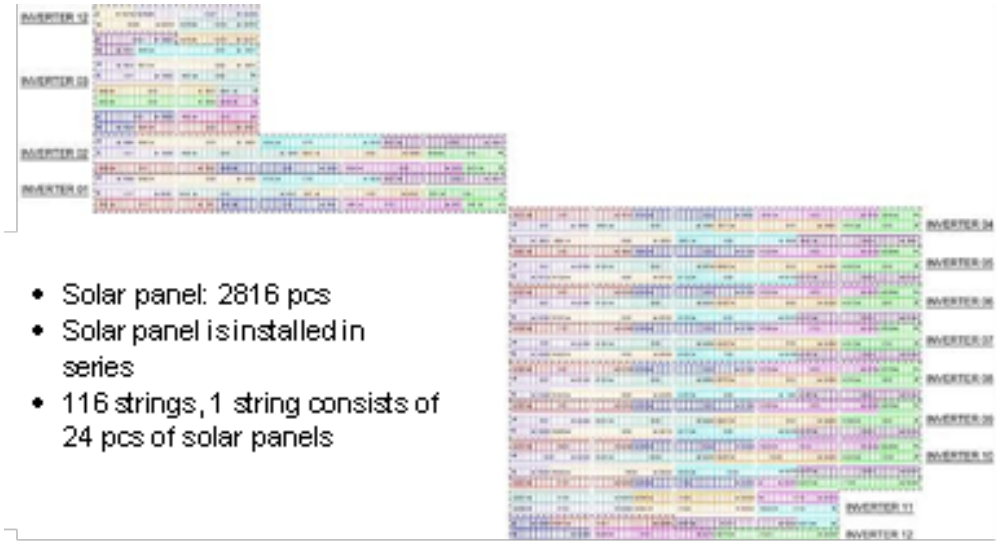


Figure 3. Grati PV placement configuration (Kenny *et al*., 2018)

Since Commercial Operation Date (COD) in August 19th, 2021 Grati 1.5 MWp *Land-based* Bifacial PV has generated 5.52 GWh, where each of them is 675.93 MWh (August – December 2021), 2,355.13 MWh (2022) and 2,485.41 MWh (2023). Refer to the result, Grati 1.5 MWp *Land-based* Bifacial PV has had the better performance than its planning.

During the operation, the authors see that there are still opportunities to improve the performance of PV by increasing its production, where it is aimed to the bifacial modules. The way is maximizing the irradiance absorption of bottom surface of the bifacial modules by engineering the albedo and do the simulation for getting its projection.

A. Albedo

Albedo is a reflection ability of sunlight from the earth's surface back into space. This ability depends on the characteristics of the earth's surface. The more sunlight reflected into the space is higher the albedo. The albedo value is a dimensionless number and it's measured on a scale from 0 to 1. Albedo is not a constant, but it varies with the spectral and angular distribution of the sunlight. These variations result from a changing sun position due to time of day, season, and latitude, and whether it is cloudy or sunny (Marion, 2020).

Low albedo is usually indicated by dark surfaces and otherwise the bright surfaces will have the high albedo. The albedo various is given figure below.

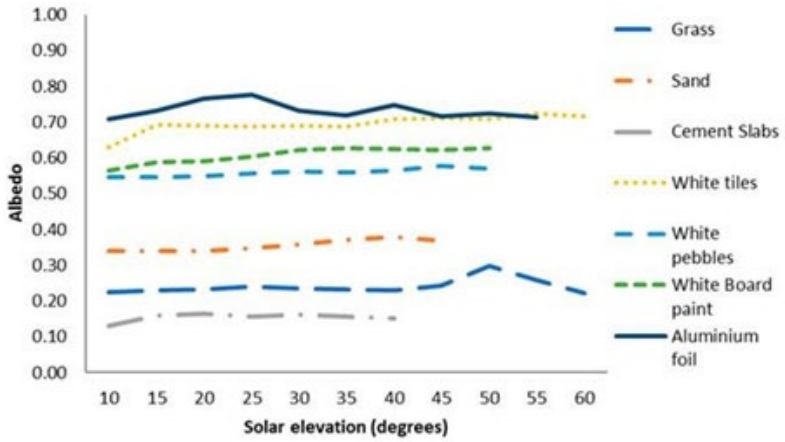


Figure 4. Albedo value on the surface types (Gul *et al*., 2018)

Following are the albedo values and how bifaciality works.

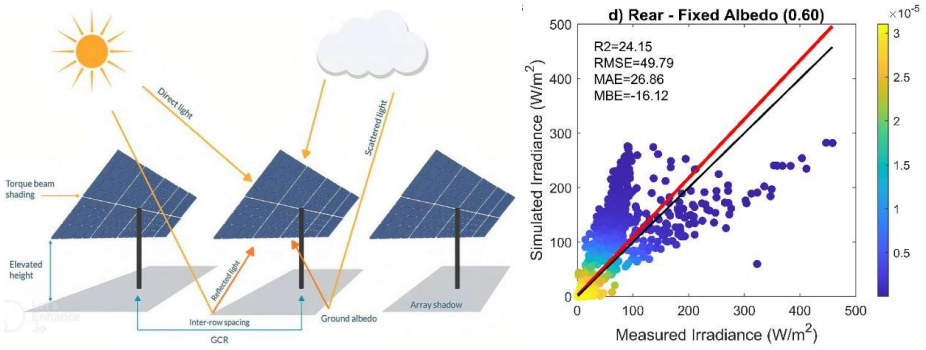


Figure 5. Albedo and how bifaciality works (Nygren & Sundström, 2021)

For example, the albedo of white coral or pebbles in various conditions has a value between 0.5 to 0.6. Although white pebbles have scattered ground reflected radiation, the albedo value increases with some sun height (Gul *et al*., 2018).

As prior research, the usage of white ground sheet as a reflector for bifacial modules increase the performance about 0.25% per m² or 3% on that modules (Kenny *et al*., 2018), where the white ground sheet is relatively similar with white coral.

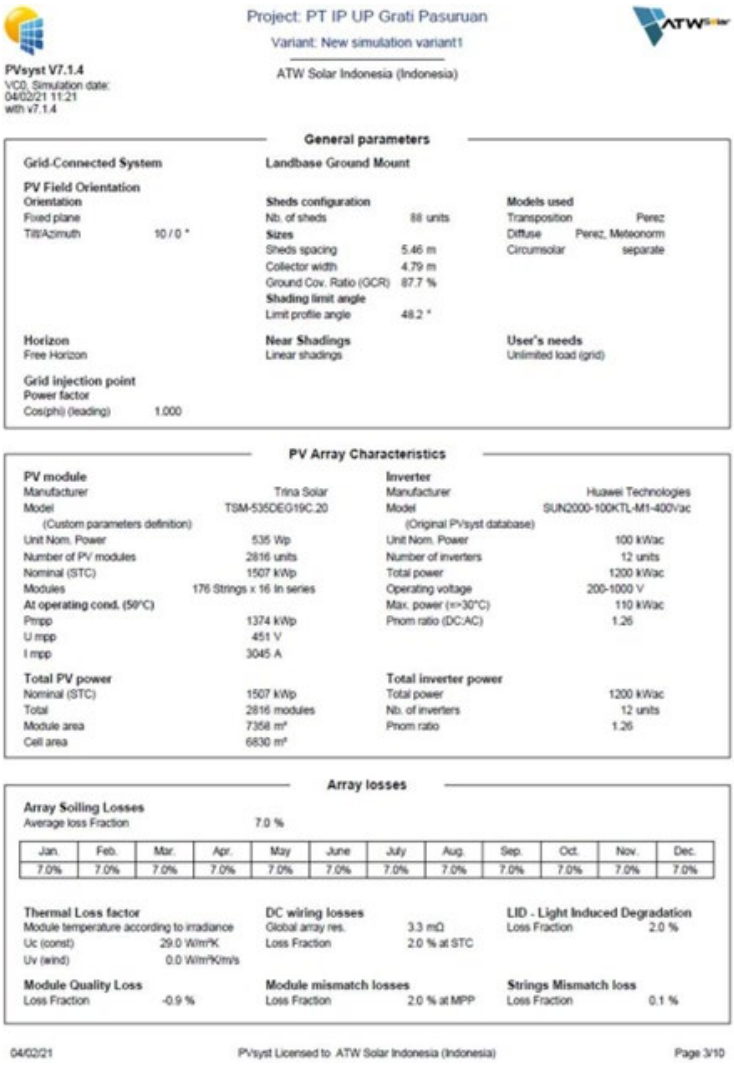
In the case of optimizing a Bifacial PV, a material which is bright color is chosen as a reflector by purposing to give the optimum reflection so that the irradiance to be absorbed by the bottom surface of the PV can be maximum.

In this study, the white coral is chosen as a reflector due to its high albedo value, available and low price. The experiment will be carried out at inverter no. 1.

Figure 6. Location of white coral placement (PLN Indonesia Power, 2021)

B. Simulation

Simulation is done by using software PVsyst. The data specification of Grati 1.5 MWp Land-based Bifacial PV is given as its input, where the total capacity is 1507 kWp with each capacity is 535 Wp/unit and 2816 monocrystalline PV modules.



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Project: PT IP UP Grati Pasuruan
Variant: New simulation variant1
ATW Solar Indonesia (Indonesia)

General parameters

Grid-Connected System — Landbase Ground Mount

PV Field Orientation: Fixed plane, Tilt/Azimuth 10 / 0 °
Sheds configuration: Nb. of sheds 88 units
Sizes: Sheds spacing 5.46 m; Collector width 4.79 m; Ground Cov. Ratio (GCR) 87.7 %
Shading limit angle: Limit profile angle 48.2 °
Models used: Transposition Perez; Diffuse Perez, Meteonorm; Circumsolar separate
Horizon: Free Horizon
Near Shadings: Linear shadings
User's needs: Unlimited load (grid)
Grid injection point: Power factor, Cos(phi) (leading) 1.000

PV Array Characteristics

PV module: Manufacturer Trina Solar; Model TSM-535DEG19C.20 (Custom parameters definition); Unit Nom. Power 535 Wp; Number of PV modules 2816 units; Nominal (STC) 1507 kWp; Modules 176 Strings x 16 In series; At operating cond. (50°C): Pmpp 1374 kWp, U mpp 451 V, I mpp 3045 A
Inverter: Manufacturer Huawei Technologies; Model SUN2000-100KTL-M1-400Vac (Original PVsyst database); Unit Nom. Power 100 kWac; Number of inverters 12 units; Total power 1200 kWac; Operating voltage 200-1000 V; Max. power (<=30°C) 110 kWac; Pnom ratio (DC:AC) 1.26
Total PV power: Nominal (STC) 1507 kWp; Total 2816 modules; Module area 7358 m²; Cell area 6830 m²
Total inverter power: Total power 1200 kWac; Nb. of inverters 12 units; Pnom ratio 1.26

Array losses

Array Soiling Losses: Average loss Fraction 7.0 %

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%

Thermal Loss factor: Module temperature according to irradiance; Uc (const) 29.0 W/m²K; Uv (wind) 0.0 W/m²K/m/s
DC wiring losses: Global array res. 3.3 mΩ; Loss Fraction 2.0 % at STC
LID - Light Induced Degradation: Loss Fraction 2.0 %
Module Quality Loss: Loss Fraction -0.9 %
Module mismatch losses: Loss Fraction 2.0 % at MPP
Strings Mismatch loss: Loss Fraction 0.1 %

04/02/21 — PVsyst Licensed to ATW Solar Indonesia (Indonesia) — Page 3/10

Figure 7. Sample of simulation input (Source: PVsyst, PLN IP PV project)

The condition refers to a prior document of PVsyst simulation. The lower temperature for absolute voltage limit is set to 20 degrees Celsius on the simulation, then the plane tilt is made to 10 degrees and the azimuth is 0 degree, which is the same as the Grati PV conditions.

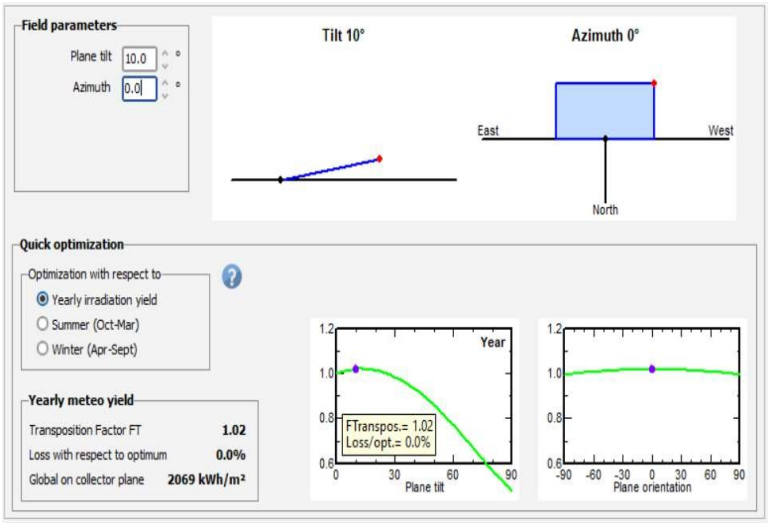

Figure 8. Setting of field parameter

The simulation trial applied on inverter 1 where it has 128.4 kWp total module capacity which consists of 24 PV modules of 535 Wp with 10 MPPT and connected in series, while an additional variable related to white coral is inserted as well.

2. EXPERIMENTAL METHOD

A. Field Experiment

In this case, the white coral is applied below modules that is connected to inverter no. 1, where it is chosen due to it having larger space. So that the irradiance which reaches the white coral will be reflected to the bottom side of that modules optimum.

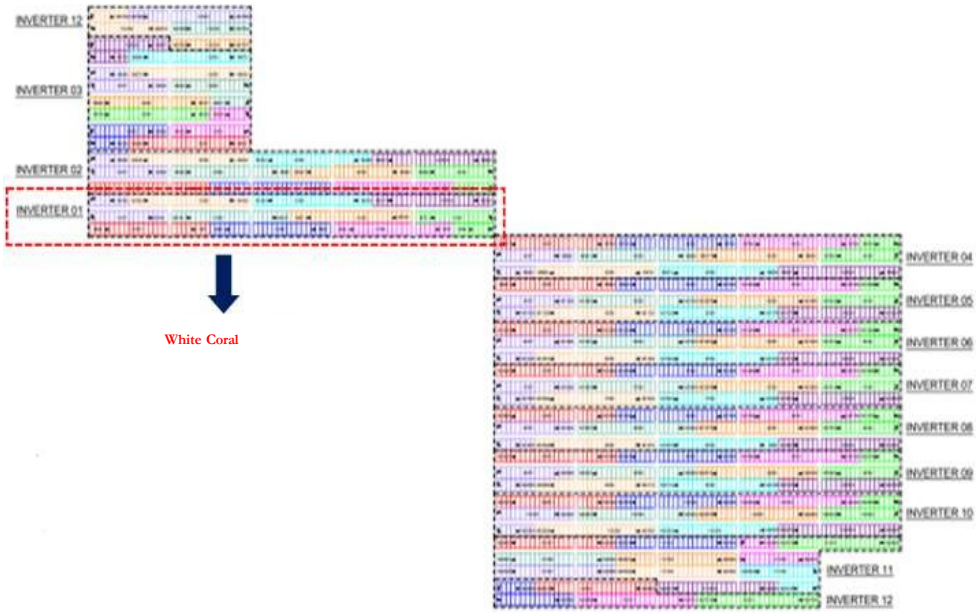

Figure 9. White coral placement (Source: PVsyst, PLN IP PV project)

The white coral is placed as long as panels of inverter 1 connection. They are arranged as large as panel's width dimension that is bordered by concrete.

Figure 10. White coral arrangement

The laying of the white coral under the bifacial solar panel module on inverter 1 was carried out on September 20th, 2022.

B. Production Measurement

The production of PV is measured by kWh meter that is installed already. The increment in production will be compared by other inverters where the average production is considered.

C. Research Sequence

The research is begun by searching literatures from journals, articles which are related to bifacial PV, to find the information about bifacial utilization. Then do simulating the PV with white coral reflector which is placed below the modules. The simulation purposes to obtain the initial projection of PV production increment. After that, field experiment is done by spreading the white coral below the bifacial modules, by attending the sun movement to acquire the maximum irradiance which is reflected to the modules.

After white coral is placed, the observation is done by monitoring the PV production through the website *http://grtsurya.indonesiapower.co.id:82/* to see and compare the inverter which the modules are placed with the white coral and other inverters. In the end, the production of each inverter will be recorded for one year and calculated to see what happen to the inverters which the modules are placed with the white coral and compare it to the other inverters. Then is acquired that how the white coral impacts to the PV production.

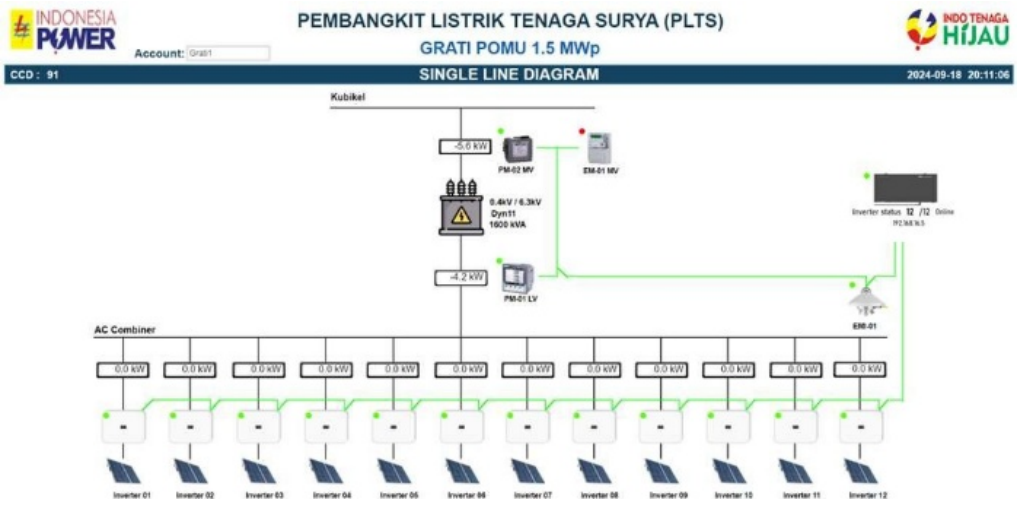

Figure 11. Inverter production monitoring by website

D. Limitation of Study

The research is done by placing the white coral under PV modules which is connected to inverter no. 1 and recording the data of the PV production that is available on the measuring panel. The research didn't measure the albedo value directly, while the albedo value is default taken from journals. The percentage of PV production increment is done by comparing the inverter no. 1 with the average production in other inverters, except inverter no. 12.

3. RESULTS

Based on the PVsyst simulation, the albedo of soil which is 0.08 acquires 227,779.0 kWh/year total production, while the albedo of white coral which is 0.6 acquires 228,284.0 kWh/year total production.

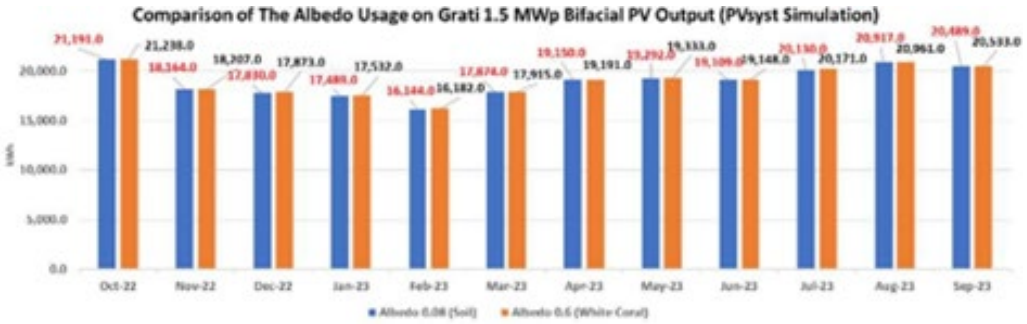

Figure 12. Energy production between soil and white coral albedo.

The PVsyst simulation results for energy production by using white coral are greater because the optimization of solar energy reception on bifacial solar panels is greater than the existing albedo (soil). The following are the PVsyst simulation results of the relationship between albedo and bifacial solar panel output.

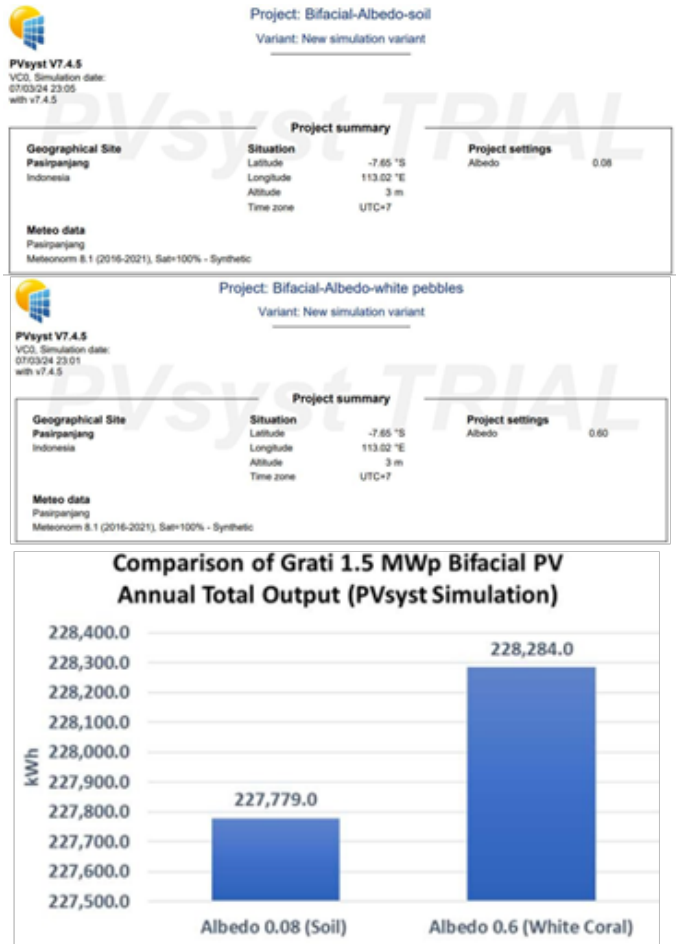

Figure 13. PVsyst simulation results of the relationship between albedo and bifacial solar panel output

By the simulation, the white coral albedo gives the production increment about 0.2% higher than soil albedo. Meanwhile, the actual production is given by measurement of kWh meter that is installed already. The measurement was carried out on inverter no.1, where the result is given as following:

Figure 14. Comparison of actual output between soil and white coral albedo

The albedo of soil acquires 210,984.9 kWh/year total production, while the albedo of white coral acquires 219,008.3 kWh/year. The increment of production is caused by more irradiance which is reflected from the white coral. It can be proven by the comparison the sunlight which is reflected from the reflectors.

Figure 15. Comparison of reflected irradiance between soil and white coral

The sunlight reaches the bottom side of PV, where the panels are brighter when the white coral is applied than the soil. It means that the irradiance to be absorbed by the PV is higher. So that the utilization of white coral succeeds in increasing the PV production.

Usage of white coral on that experiment costs Rp. 74,360,000. Based on the production results after using white coral, it succeeded in increasing the kWh output of bifacial solar panels. The kWh output increment of bifacial solar panels for 1 year is around 8,023.4 kWh, resulting in IDR 15,924,362.92 cost saving (1 inverter/year). The project of improving albedo with white coral has given the Return of Investment (ROI) about 5 years, and it is potentially extended for whole modules.

4. DISCUSSION

This research examines the improvement of albedo values to increase energy production of Grati 1.5 MWp PV using bifacial solar panels, where the simulation on PVsyst shows that a positive relationship between albedo and energy output. Kenny *et al.* (2018) reported that the white coral which can be similarized by the white ground cover will help to increase the bifacial PV production until 3%.

By simulation, soil material with an albedo value of 0.08 produces an energy output of 227,779 kWh per year, while white coral with an albedo value of 0.6 produces an energy output of 228,284

kWh per year. This shows that materials with high reflectivity can increase solar energy reception in bifacial solar panels. The implementation of white coral under the solar panels on inverter 1, which has a total module capacity of 128.4 kWp, was carried out on September 20th, 2022. The results of the evaluation for one month showed an average output increase of 4.4%, while the evaluation for one year showed an increase in output of 3.8%, from 210,984.9 kWh to 219,008.3 kWh.

The usage of white coral on that experiment costs Rp. 74,360,000 but resulted in an annual output increase of 8,023.4 kWh, which is equivalent to IDR 15,924,362.92 cost saving per inverter per year. Apart from that, the implementation of white coral as reflector of Grati 1.5 MWp *Land-based* Bifacial PV can give the economic profit in form of reasonable and interesting ROI. Therefore, the strategy of increasing albedo with reflective materials such as white coral can be adopted to significantly increase the efficiency and energy output of solar PV, making it a feasible solution to be implemented to increase sustainability and energy efficiency in bifacial solar panel installations.

5. CONCLUSION

Based on the results of the analysis above, it can be concluded that the utilization of white coral stone has been proven to increase the Bifacial PV production. The reflective properties of a material are determined by how clear it. Brighter materials will help to reflect the sunlight higher than the darker materials. It is in accordance with the characteristic of colour, where the bright colours can reflect the light while the dark colours can absorb it. In case of improving the Grati 1.5 MWp Bifacial *Land-based* PV, it has been proven to increase the irradiance which is reached to bottom side of the bifacial PV panels that is indicated by the 3.8% increment of PV production. Implementation of white coral has given benefit for the company especially in reducing imported power consumption. So, this improvement is very important and has high potential for developing to all inverters.

6. ACKNOWLEDGMENT

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