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Integrating PV plant 689 kWp into Coal-Fired Power Plant (CFPP) 615 MW at Paiton: To reduce auxiliary load and coal consumption

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ABSTRACT

Integrating solar energy into a coal-fired power plant is a promising way to reduce auxiliary load and numerous environmental issues related to the coal-based power generation sector. This paper will discuss the annual performance of PV plant 689 kWp at ash disposal that integrated into 615 MW coal-fired power plant PT xxx, including an estimate of total potential energy that can be generated; analysis of auxiliary load to improve performance and decreasing pollutant emissions by coal consumption reduction. The PV Plant has been operated for at least 2 years, built on an area of 5,000m2, is an On-grid PV Plant system with 11 grid Inverters and has 2,120 solar modules installed. Based on the simulation using Helioscope software, it can generate electrical energy up to 977,442 kWh per year with a performance ratio of 79.3%. The result of the PV plant utilization evaluation shows the amount of electrical energy produced is 1,096,105 kWh in 2021, above the estimation from the simulation. This result means auxiliary power load was decreasing by 0.4932%, It is also considered to be able to save the use of 263.065 kilolitres per year of diesel and also save the use of coal up to 386.634 tons or equivalent to 0.007% coal consumption per year. From an environmental point of view, it is also assessed to reduce CO2 emissions equivalent to 920.729 tons/year and the equivalent of planting 4,602 trees per year.

Keywords: Energy; PV Plant; CFPP; Paiton; Emission Coal

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1. INTRODUCTION

Energy is one of the natural resources that has strategic value for sustainable national development [1]. There are many various types of energy such as fossil-based energy and non-fossil-based energy [2]. Recently, the scarcity of fossil-based energy such as fuel oil, coal, and natural gas and environmental issues of its utilization trigger the diversity of non-fossil-based energy utilization to substitute fossil-based energy [3]. As one of the strategies for diversity, hybridization is a potential approach [4]. It integrates coal-fired power plants (CFPP) and solar energy to encounter environmental issues such as pollutant emissions and decrease coal consumption [5].

Hybridization consists of two sources of energy; main and auxiliary. The fossil-based energy is the main source and solar energy is the auxiliary thermal source. This approach is common in the system and their impact includes environmental from power generation [6]. Solar energy is selected since Indonesia's position on the equator allows sunlight to be optimally received in almost all of Indonesia throughout the year, with an average power of > 4 kWh/m^2/day [7]. With this condition, solar-aided power generation is very possible [8].

In recent years, intensive research on the hybridization of CFPP and PV Plant has been accomplished in many different methods [9]. Among all methods was using solar energy for thermal energy storage [10] [11] [12] [13] [14]. The PV Plant system is a power generation system connected to the network or On-Grid system, so they only supply during the day [15]. In the utilization of PV Plant On-grid as a backup power plant, the power produced by solar energy by panels is unstable because it depends on the intensity of sunlight received by the solar panels [16].

This paper will discuss the annual performance of PV plant 689 kWp at ash disposal that integrated into 615 MW coal-fired power plant PT xxx, including an estimate of total potential energy that can be generated, analysis of auxiliary load to improve performance, and decreasing pollutant emissions by coal consumption reduction. This study can assist CFPP to prepare a coal switching program to optimize their performance and estimation of coal consumption.

2. MATERIAL AND METHODS

2.1 Literatur review

This method is used to know about the PV plant and CFPP by the collection of document data, regulations, records and final reports related to solar energy power generation.

2.2 Field observation and recording

This method is used to collect data and information about PV Plant systems and CFPP by measurement and recording of electrical energy through an inverter.

2.3 Energy generation analysis

This analysis method is to compare the initial planning for the installation of PV plant with the actual condition locally. The evaluation carried out is by comparing the estimated generation results during the project and the metering results after the PV plant from January 2021 until December 2021.

2.4 Energy contribution analysis

This analysis method is to calculate the contribution of PV plant generation with CFPP Auxiliary Power load. The evaluation was carried out to identify PV plant impact on CFPP generation.

$$\text{Contribution (\%)} = \frac{\text{E PVplant + Aux.load}}{\text{Aux.load}} x100\% \quad (1)$$

2.5 Emission factor

To figure out the potential for the emission factor is carried out with the following equation:

CO_2 Saved Equivalent = Total Energy/year (Solar Panel) x Emission Factor (FE) (2)

CO_2 Saved Equivalent = E PV plant (MWh) x 0.84 tonCO_2eq

Where:

FE = 0.84 tonCO_2eq

Total Energy = E PV Plant Electrical Generation in 1 year

2.6 Trees planted equivalent

To figure out the potential for trees planted equivalent is carried out with the following equation:

Trees planted Equivalent = trees planted equivalent x CO_2 Saved Equivalent (3)

Trees planted Equivalent = 4,999 trees/tonne x CO_2 Saved Equivalent

Where:

Trees equivalent = 4,999 trees for every 1 ton CO_2

2.7 Fuel oil saving

To figure out the potential for fuel oil saving is carried out with the following equation:

Fuel Liter equivalent = Total Energy/year (Solar Panel) x HSD equivalent (4)

Fuel Liter equivalent = E PV Plant (MWh) x 0.240 kl HSD eq

Where:

HSD fuel equivalent = 0.240 kl HSD eq

Total Energy = E PV Plant Electrical Generation in 1 year

2.8 Coal saving

To figure out the potential for coal saving is carried out with the following equation:

Coal saved = Total Energy/year (Solar Panel)/ coal equivalent (5)

Coal saved = E PV Plant (MWh) / (2.460 MWh/tonne)

Where:

The standard coal equivalent is 2,460 kWh per ton

Coal Equivalent = 2.460 MWh/tonne
Total Energy = PV Plant Electrical Generation in 1 year

2.9 Flowchart for Saving Auxiliary Load and Coal Consumption

The sequence for savings is shown in Figure 1. Savings are calculated by the equation above and analysis about it.

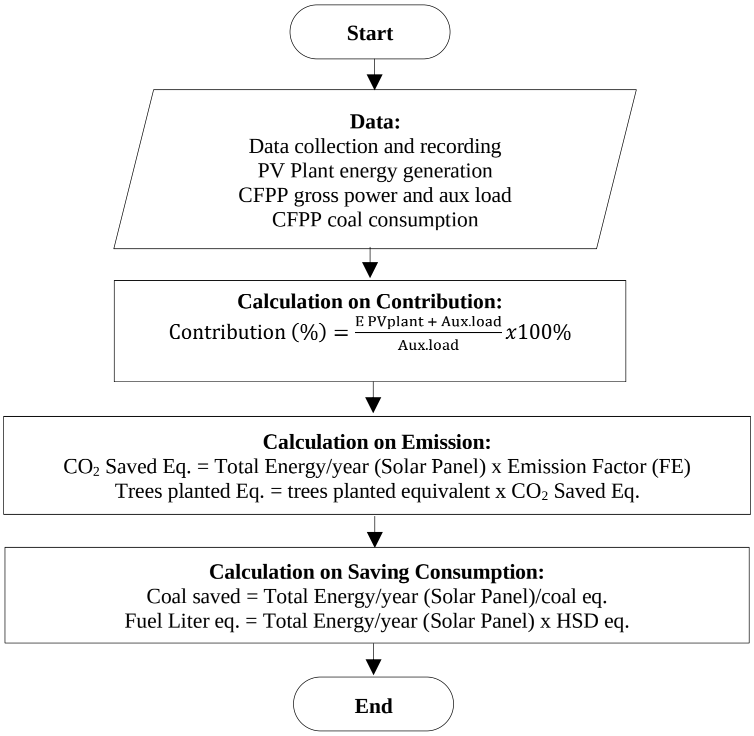

Figure 1 : Flow chart for calculating savings

3. RESULTS AND DISCUSSION

3.1 PV plant location

An ash disposal area is a place for the disposal of ash waste or ash piles at PT. POMI. Its main use apart from being a place for ash disposal is as an office on the other side of the ash disposal area. PV PLANT Installation profile with details in table 1:

Table 1 : Fuel efficiency calculation results

No.	Description	Value
1	Location	Ash disposal PT. POMI, Paiton Kab. Probolinggo, Provinsi Jawa Timur
2	Latitude	-7.7177728 ^{0}
3	Longitude	113.5689953 ^{0}
4	Altitude	25-100 MDPL
5	Tilt angle	GMS = 100 (flush mount) BMS = 150 (fixed tilt)
6	Azimuth	Horizontal 0 ^{0}
7	Area	± 5,000 m^2

3.2 PV plant installation

An ash disposal area is a place for ash disposal in an office on the other side of the ash disposal area. Because there are buildings that operate 24 hours, electrical energy is needed to keep them awake. Electricity PT. The POMI at Ash disposal is from unit 7 PS bus B transformer 13.8 KV network, which is then channelled to the ash disposal area. At Ash disposal itself, the network has two branches, namely one branch for the purpose of supplying fly ash conveyor loads and another branch for supplying electricity for warehouses, Coal Labs, Paving block Plants, and the Core Team (firefight) building as shown in figure 2.

Figure 2 : PV Solar Plant satellite imagery

To reduce dependence on auxiliary transformers, an on-grid PV Plant is designed at the ash disposal location. Particularly when unit 7 is shut down for overhaul, it is the last priority in loading, so it uses a generator for daily operations as shown in figure 3.

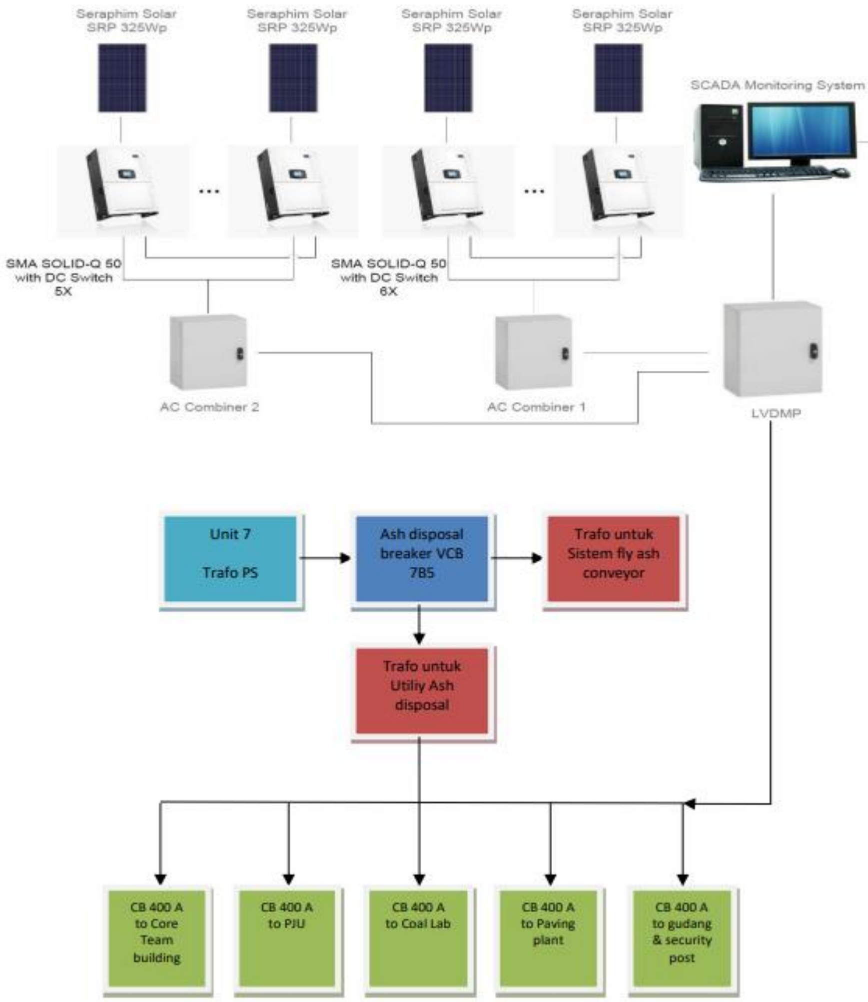

Figure 3 : Schematic diagram PV solar plant at ash disposal

There are 2,120 PV modules which are divided into 11 inverters, with details of inverters no. 1 and 2 consisting of 160 PV modules per inverter. Meanwhile, inverters 3 to 11 consist of 200 PV modules per inverter. Inverter no. 1 and 2 have a capacity of 52 kWp, while the other 9 have a capacity of 65 kWp. Then every 1 PV array contains 40 PV modules so that each inverter consists of 4 to 5 PV arrays. PV array is instaled by Ground Mounting System (GMS) in figure 4 (a) and Ballasted Mounting System (GMS) in figure 4 (b).

(a) (b)

Figure 4 : (a) PV array with Ground Mounting System (GMS) instalment and (b) PV array with Ballasted Mounting System (BMS) instalment

3.3 Helioscope simulation result

PV Plant estimation generation capacity was obtained from the software helioscope. It is possible to calculate the energy potential generated in one year as shown in figure 5 and table 2.

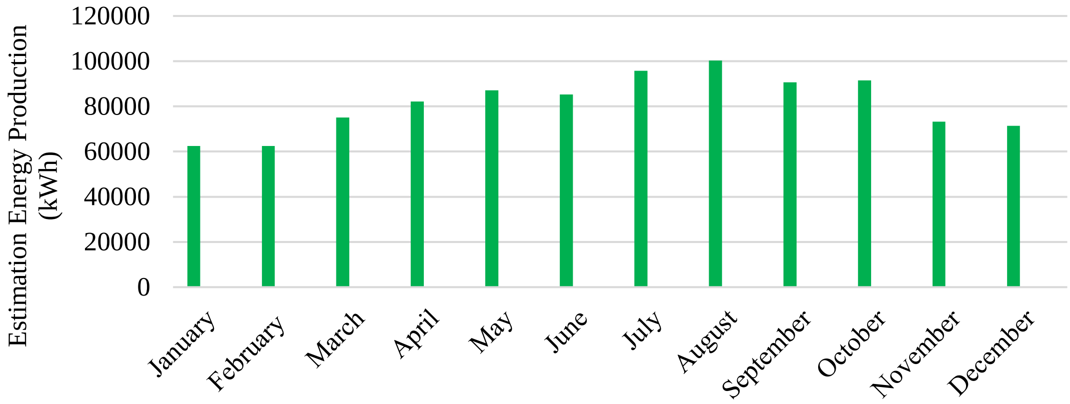

Figure 5 : PV Plant energy potential generated every month

Table 2 : PV Plant irradiance and energy potential generated in 1 year

	Description	Output	%Delta
	Annual Global Horizontal Irradiance	1749.1	
	POA Irradiance	1,789.4	2.3%
Irradiance (kWh/m2)	Shaded Irradiance	1,771.2	-1.0%
	Irradiance after Reflection	1,712.9	-3.3%
	Irradiance after Soiling	1,678.6	-2.0%
	Total Colector Irradiance	1,678.6	0.0%
	Namplate	1,157,486.7	
	Output at Irradiance Levels	1,152,995.7	-0.4%
	Output at Cell Temperature Derate	1,046,210.1	-9.3%
Energy (kWh)	Output After Mismatch	1,008,559.0	-3.6%
	Optimal DC Output	1,003,396.5	-0.5%
	Constrained DC Output	1,002,420.8	-0.1%
	Inverter Output	982.353,0	-2.0%
	Energy to Grid	977.442,0	-0.5%

3.4 Actual PV plant generation result

Actual data (metering) of 689 kWp instalment capacity were collected daily and then tabulated for 1 month from January 2021 to December 2021 by details as in table 3.

Table 3: Actual energy generation

No	Month	Energy Generation (kWh)	Peak (kW)	Run Time (Hour)
1	January	70,994	476.723	3,490
2	February	71,033	481.978	3,101
3	March	101,167	534.473	3,673
4	April	97,486	530.080	3,616
5	May	95,929	509.524	3,702
6	June	88,623	494.907	3,560
7	July	98,702	510.421	3,705
8	August	106,792	515.620	3,732
9	September	106,594	534.508	3,661
10	October	113,801	532.843	3,850
11	November	63,467	533.537	2,820
12	December	81,520	532.875	3,916
	Total	**1,096,105**		**42,826**

Further, actual energy generation (obtained by metering) and simulation of the PV plant by Helioscope are compared. The actual total energy generation of PV Plant monthly in a year and a comparison between actual and simulation results are shown in figure 6.

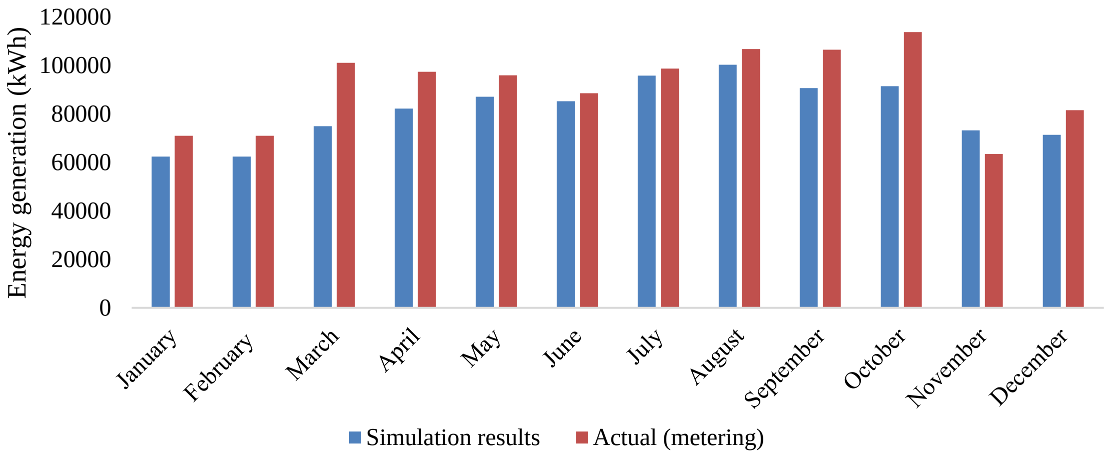

Figure 6: Energy generation of PV plant between simulation results and actual

The actual energy generation (metering) is higher than the simulation, it is because the PV Plant installed is new and the surface of the PV module is clean. The highest kWp by this PV Plant system is 534.473 kWp. It is under the peak value of the system due to the intensity and the shadows of plants or buildings blocked the light from the PV Module. Another justification, kWh distributed to the grid in simulation is estimated at 977,442 kWh, meanwhile, the actual data by metering is higher (1,096,105 kWh).

3.5 Auxiliary load power reduction

The result of the integrated PV plant as an auxiliary thermal source into CFPP is shown in table 4.

Table 4: Result of integration CFPP plant and PV Plant

No	Month	Gross Power (MWH)	Aux Power (MWh)	PV Plant (MWh)	NPHR (kCal/kWh)	Contribution (%)
1	January	452.985	17,181.99	70.994	2,466	0.4115
2	February	326.200	16,709.87	71.033	2,457	0.4233
3	March	303.144	26,006.57	101.167	2,512	0.3875
4	April	433.061	22,906.52	97.486	2,483	0.4238
5	May	453.419	23,805.78	95.929	2,476	0.4013
6	July	430.074	21,882.33	88.623	2,485	0.4034
7	June	373.303	24,592.27	98.702	2,474	0.3998
8	August	423.359	16,996.50	106.792	2,471	0.6244
9	September	310.537	16,009.44	106.594	2,479	0.6614
10	October	366.750	23,913.33	113.801	2,476	0.4736
11	November	-	-	63.467	-	-
12	December	334.362	11,132.85	81.520	2,462	0.7269
	Total	**4,207.194**	**221,137.45**	**1,096.105**	**2,476**	**0.4932**

The integration of the PV plant as an auxiliary thermal source into CFPP based on table 3 obtained auxiliary load power reduction. The PV plant contributed 0.493% to the reduction. That means if a power plant is equipped with PV Plant as support of an auxiliary thermal source can increase more power into the grid system. Thus, the power plant is more efficient in heat rate. In this study, PV plant can contribute to reducing 12 kCal/kWh every day.

3.6 Environmental impacts

PV plant integration into CFPP results in auxiliary load power reduction. It decreases coal consumption, thus increasing the environmental quality in terms of reducing CO_2 emissions and trees planted. Estimation results of CO_2 saved, fuel and coal saved, and trees planted are in table 5.

Table 5: Environmental impact of integration PV plant into CFPP plant

No	Month	Energy (kWh)	CO_2 emission reduction (tCO^2eq)	Fuel Saved (kl eq)	Trees Planted (Trees Eq)	Coal Saved (ton Eq)
1	January	70,994	59.635	17.038	298.1	28.859
2	February	71,033	59.667	17.048	298.3	28.875
3	March	101,167	84.980	24.280	424.8	41.125
4	April	97,486	81.888	23.397	409.4	39.628
5	May	95,929	80.580	23.023	402.8	38.995
6	June	88,623	74.443	21.269	372.1	36.025
7	July	98,702	82.910	23.689	414.5	40.123
8	August	106,792	89.705	25.630	448.4	43.411
9	September	106,594	89.539	25.582	447.6	43.331
10	October	113,801	95.593	27.312	477.9	46.261
11	November	63,467	53.312	15.232	266.5	25.800
12	December	81,520	68.476	19.565	342.3	33.138
	Total	**1,096,105**	**920.729**	**263.065**	**4,602.7**	**386.634**

The estimation results in table 4 informed that integration of PV plant into CFPP plant increases environmental quality such as reduction of CO_2 emission and saving of fuel, coal and trees planted. PV Plant Ash disposal has played a role in reducing CO_2 equivalent by 920.729 tons during 12 months of operation in 2021. It reduces the average of 76.727 tons/month with the highest beings 95.593 tons/month and the lowest being 59.635 tons/month. The integration also saves diesel fuel consumption as much as 263.065 kl during 12 months of operation in 2021. The average of saving fuel is 21.922 kl/month at a range of 17.038 kl/month - 27.312 kl/month. PV Plant Ash disposal also reduces coal consumption. As much as 386.634 tons of coal are saved during 12 months of operation in 2021. With an average of 38.663 tons/month at a range of 46.261 - 28.859 tons/month. Referring to the lowest data, which is 28.859 tons/month, with an average consumption of units 7 and 8 of 400,000 tons/month, it can be equated with saving coal consumption of at least 0.007% per month. PV Plant Ash disposal also saved in trees planted equivalent to 4,602 trees in 2021 with an average of 383 trees/month at a range of 477 trees/month - 298 trees/month.

4. CONCLUSION

For the generation data generated after the PV Plant has been running for 2 years, the generated data is limited to the simulation data that was planned at the beginning, 977,442 kWh to 1,014,586 kWh in 2021. It impacts to reduce 0.4932% of Auxiliary Power consumption and heat rate more efficiently. PV Plant generation is considered to be able to save 243.501 kl of diesel fuel for 11 months in 2021. And also save coal use of up to 336.634 tons or equivalent to 0.007% of coal consumption of units 7 and 8 in a year. From an environmental perspective, it is also mathematically assessed to reduce CO_2 emissions equivalent to 852.252 tons/year and the equivalent of planting 4,260 trees per year in 2021. Regarding the big difference in metering results between inverters 1 and 2 and the others, it is caused by the difference in the number of modules on inverters 1 and 2, which is 160 modules, which means 40 modules are different. It is recommended to carry out inspections and cleaning activities regularly every 2 months so that the continuity of the PV Solar Plant is maintained and its generation remains optimal. Cleaning of twigs and tree branches that have the potential to interfere with the capture of sunlight on the PV module. Rainwater drainage paths are should be made so that the soil does not erode when the rainy season come

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DECLARATIONS

Author contribution

A. Syarief: Writing - Original Draft, Writing -Review & Editing, Conceptualization, Formal analysis, Investigation, Resources, Visualization. W. Jaka: Conceptualization, Formal analysis, Investigation, Supervision. Y. W. Asep: Writing - Review & Editing, Resources, Visualization, Supervision. E. Tariq: Conceptualization, Formal analysis, Investigation.

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Competing interest

The authors declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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