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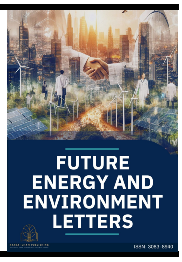
Future Energy and Environment Letters

Journal homepage:
https://karyailham.com.my/index.php/feel
ISSN: 3083-8940



Optimization of Solar Power Plant (PLTS) usage for Substitution of Internal Electricity usage in an Effort to Increase the Efficiency of Gas Engine Power Plant (PLTMG)

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ARTICLE INFO

Article history:
Received 29 March 2026
Received in revised form 30 May 2026
Accepted 2 June 2026
Available online 15 July 2026

Keywords:
Gas Engine Power Plant (PLTMG); Solar Power Plants (PLTS); self-use

ABSTRACT

Gas Engine Power Plant (PLTMG) is a type of plant that is widely used in small-scale electricity systems and in remote locations. This is because PLTMG has very flexible operating capabilities and faster startup times when compared to other traditional plants. In its operational process, PLTMG requires electricity resources to support various supporting equipment such as cooling systems, pumps, air compressors, control systems, and lighting. The electrical energy used for this purpose is referred to as the auxiliary load, which directly reduces the amount of net electricity that can be channelled to the grid, thus impacting the efficiency of the plant. One approach that can be applied to reduce the use of electrical energy in power plants is to utilize renewable energy sources, such as Solar Power Plants (PLTS), to meet some of the internal electricity needs of PLTMG. In the Bawean PLTS system, this plant is designed to provide additional power to the PLTMG machine by using the settings of the Energy Management System (EMS), which aims to make the energy produced by PLTMG can be used more optimally to support the power grid. Based on the analysis of internal electricity usage data at the Bawean PLTMG, the total internal load of the plant was recorded at 643.42 kW, which is equivalent to around 21.45% of the total capacity of the plant which reached 3 MW. On the other hand, solar power systems can produce around 100 to 120 kW of power when solar radiation conditions are at maximum levels. Assuming that operations run effectively for 6 hours every day, the electrical energy produced by solar power plants can be estimated to reach 720 kWh per day or approximately 21. 600 kWh in a month. This energy can replace about 18.65% of the plant's total internal electricity needs.

1. Introduction

Power generation systems are expected to operate reliably, efficiently, and affordably to meet the energy needs of the community [1]. In archipelagic areas or separate systems, PLTMG is one of the commonly used plant options because it has the ability to start operating quickly and flexibility in its operation. However, the real efficiency of a plant depends not only on the capacity of the main

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engine to generate power, but also on the amount of electrical energy required to support the internal operation of the plant [2,3].

In a gas-engine-based plant, there are various supporting equipment that needs to operate in order for the unit to remain reliable. The equipment includes radiator fan motors, engine heaters, preheating pumps, power sources for control, air compressors, lighting, and various loads from support panels. The higher the electricity usage by this supporting equipment, the less clean electrical energy can be delivered to the grid. In terms of system efficiency, energy consumption itself needs to be considered an important variable as it directly reduces the net output of the plant [4].

Efforts to improve the efficiency of the plant are often focused on aspects of the engine, such as improving the heat rate, optimizing the combustion process, or maintaining key parts. However, from an operational perspective, the reduction of internal load can also have a significant impact [5] . This is where the use of solar energy becomes relevant. When solar power is integrated to meet the internal needs of the power plant, the energy generated by the solar power plant is not fully used by the supporting equipment. As a result, the clean energy that can be sent to the system increases without the need to increase the output of the main engine [6,7].

Bawean Solar Power Plant is designed to supply additional power to each PLTMG machine through an EMS system and batteries. The RCFA document states that this system consists of three PV systems with a battery system regulated by EMS to provide additional power to each PLTMG machine [8], [9]. However, the same document also shows that during the operation phase there is still excess power that interferes with system stability, so that the optimization of solar power utilization is not only seen from the presence or absence of power contribution, but also needs to be evaluated from the aspect of control and its suitability with the internal load profile [10], .

This study aims to analyze how much the burden of self-use from the Bawean PLTMG is, assess the extent to which the PLTS can replace the load, and assess its impact on the efficiency of the plant's operations. The main focus is to answer three questions: how much of the PLTMG's internal load, how much of that load can be replaced by PLTS, and how much of the operational efficiency improvement can be expected from this scheme [11,12].

2. Methodology

2.1 Research Workflow Framework and Strategy

This research not only provides an explanation of the research objectives, but also uses a quantitative and evaluative approach based on literature research, problem identification, operational data collection, and technical analysis [8,13]. The research begins by determining the boundaries, focus, and objectives related to the integration of Solar Power Plants (PLTS) into the internal system of PLTMG. After that, the research continues by reviewing literature and identifying problems to determine the variables and analysis methods to be used [8].

Data were collected in two main parts: operational data from the PLTMG to determine internal electricity needs and PLTS data to assess energy production potential. Based on this data, calculations were carried out for the PLTMG's self-consumption load and an analysis of PLTS energy production in kilowatt-hours [14]. Next, the contribution of the PLTS in replacing a portion of the PLTMG's internal load was calculated, followed by an efficiency analysis [1]. Afterward, all research results were evaluated and discussed to assess their significance and impact. Ultimately, it was concluded that the PLTS is effective as a solution to meet part of the internal electricity needs of the PLTMG.

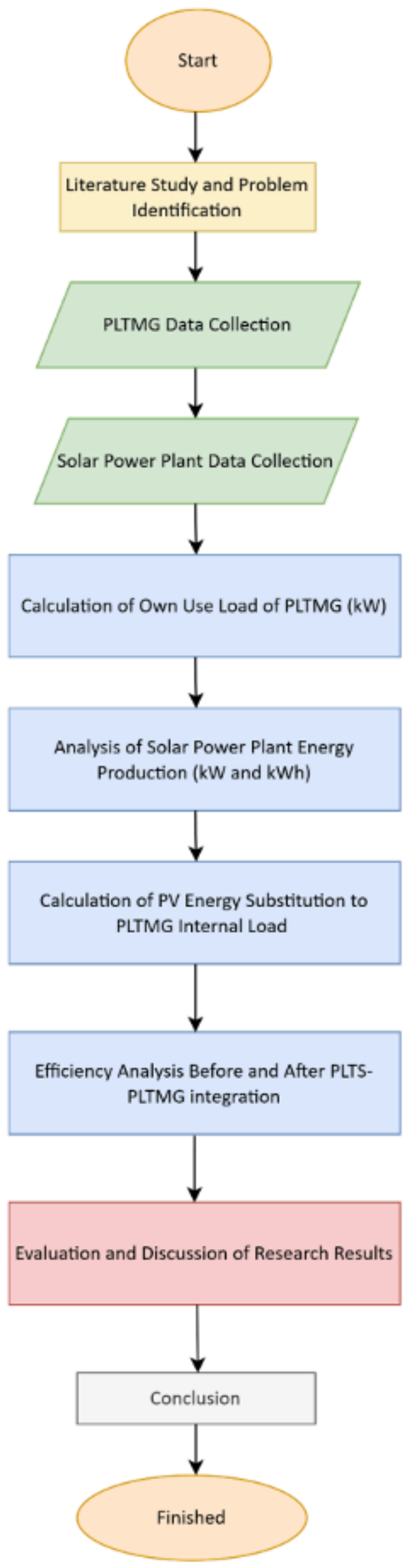

Fig. 1. Research flowchart

2.2 Research Place

The object of research is the Bawean PLTMG system along with the PLTS system that supports and integrates to meet the internal power needs of the plant. The Bawean PLTMG is a plant that uses gas engines and functions to meet the electricity needs of Bawean Island, which is located in Gresik Regency, East Java. In carrying out its operations, this plant requires electrical energy for the operation of supporting equipment called self-use which includes cooling, lubrication, ventilation, lighting, as well as control systems and instruments.

The solar power system in the power plant area consists of photovoltaic modules, inverters, and monitoring devices, which are specifically tasked with providing some of these internal power needs. This research focuses on two main aspects: the analysis of the size and characteristics of PLTMG's own use, and the analysis of the contribution of solar PV in meeting the internal load.

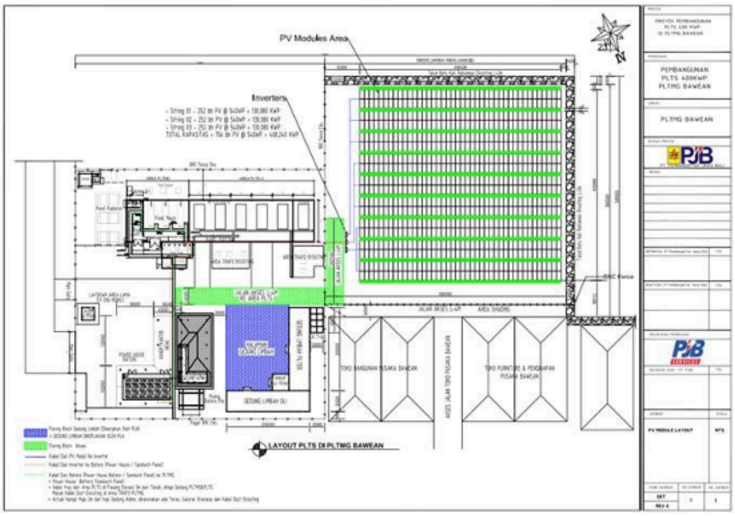

Fig. 2. Layout of the power plant area plan
Note: As a data source, the image still uses Indonesian, like the company's original documents.

2.3 Data Sources

This research uses secondary data from technical reports, operational documents, and equipment specifications related to gas engine power plant (PLTMG) and solar power plant (PLTS) systems in Bawean. This data is used as a basis to analyze system performance and assess the contribution of PLTS in meeting the internal load requirements of the power plant. In general, the research data sources can be divided into three main groups, namely:

2.3.1 Self-consumption data (PS) Bawean PLTMG

The data source for self-consumption (PS) is the operational document of the Bawean PLTMG. This document contains information about all energy-consuming equipment, as well as the power capacity of each piece of equipment. This data shows the amount of energy required to support the operation of the internal power plant. The data includes several important parameters, such as the names of the equipment used in the power plant system, the installed power (kW) of each piece of equipment, the number of equipment units, the total power of the equipment, and the power consumption when the PLTMG units are operating (running) or off, and the total power consumption for the three PLTMG units. It is used to measure the internal load profile of the generator and identify the equipment.

2.3.2 Solar module specification data

Solar module specification data were taken from the official datasheet of the LONGi LR5-72HPH module, which has a power range of 540–560 W, containing technical information used to check the performance and characteristics of the solar system. The parameters used in this study are as follows: maximum power (Pmax), module efficiency (%), open-circuit voltage (OCV), short-circuit current (Isc), voltage at maximum power point (Vmp), current at maximum power point (Imp)

2.3.3 PLTS system disruption data (RCFA)

Data on PLTS system disturbances were obtained from RCFA documents, which are root cause failure analyses. The date and time of the disturbance, a description of the event, and information on the impact of the disturbance on the power generation system. The data obtained from the RCFA is used to: Identify the main components causing failures in the PLTS system; Evaluate the impact of PLTS integration on the stability of the PLTMG system; and Serve as a basis for assessing the reliability of the integrated power generation system.

2.4 Stages of Analysis and Equations Used

By using operational data from the power plant, the research analysis process was carried out systematically and structured. In the initial stage, all internal usage loads also known as internal expenditure loads were identified, classified, and collected to determine the amount of internal power required to support the operation of the power plant. Auxiliary systems such as cooling systems, pumps, control systems, and other supporting electrical equipment are usually involved in these internal loads.

After determining the total internal load, the installed capacity of the PLTMG is compared to that value to calculate the self-consumption percentage. This parameter is very important because it shows how much of the generated energy is used for internal needs rather than being transmitted to the grid. Equation (1) refers to the auxiliary power consumption commonly found in power generation systems. This equation is used to calculate the percentage of auxiliary load, also known as auxiliary power.

$$AuxiliaryLoad = Paux$$
$$PPLTMG$$

$$\times 100\ \% \qquad (1)$$

where $Paux$ is the total auxiliary load power and $Ppltmg$ is the installed generator capacity.

Next, the data generated by the solar power plant (PLTS) is analyzed to determine the amount of energy that can be supplied to meet internal load requirements. This analysis looks at the characteristics of solar energy variability and whether the PLTS system matches the load demand pattern. The calculation of the energy produced by the PLTS is carried out by examining the relationship between output power and operating time. As stated in Equation (2), the main principle of electrical energy is used in this calculation.

$Eplts = Pplts \times t$ (2)

Where $Eplts$ is the electrical energy generated by the PV system, $Pplts$ is the output power of the solar system, and t is the operating time.

Next, the estimation of daily and monthly energy production is carried out to assess the consistency and reliability of solar energy production over time. Equation (3), which shows the comparison between the PV power plant output and the auxiliary load requirements, is used to calculate the level of contribution of the PV power plant to the substitution of internal loads. This estimation is used to evaluate the extent to which energy from the PV power plant can replace or reduce the internal load that was previously supplied by the main generator.

Then daily and monthly energy estimates are carried out from solar power plants that can be used to replace internal loads. The level of contribution of solar power plants to internal costs is calculated by Formula (3):

$Substitusi = PPLTS \times 100\%$ (3)
$Paux$

This parameter indicates how effective the solar power system is in reducing the amount of internally consumed energy. Then the results of all calculations are analyzed to determine the role of the solar power system in lowering the internal consumption load at the gas-steam power plant. In addition, it is examined how the integration of solar energy affects the operational efficiency of the power plant, reduces fuel consumption, and improves overall system performance. It is expected that this analysis will provide us with a better understanding of the benefits of implementing renewable energy in conventional power generation systems.

3. Results

3.1 General Specifications of PLTMG and PLTS Systems

The research results show that the power generation system in Bawean uses a hybrid integration concept between a Gas Engine Power Plant (PLTMG) and a Solar Power Plant (PLTS), which was comprehensively designed from the early planning stages [2,4]. The PLTMG, with an installed capacity of 3 MW, serves as the main generator, while the PLTS with high-power LONGi modules (efficiency up to 21.7%) serves as a supporting energy source. All of this is integrated through a Sungrow SG110CX inverter and controlled by Enectric.

The main finding of this study is that the PV system is not used as a power supplier to the external grid. Instead, it is used to meet the internal load (auxiliary load) needs of the gas turbine power plant system [3,14]. This approach demonstrates an energy optimization strategy where solar energy is used to replace the plant's internal gas consumption. Operationally, this reduces the workload of the gas turbine power plant to meet internal demands.

This integration has a significant effect from the perspective of energy efficiency. With the reduction in the internal energy consumption of the GTMPPP, gas demand also decreases. This directly improves the overall thermal efficiency of the power generation system [15]. The EMS also enables better energy distribution control according to operational conditions, which reduces losses and enhances system performance in real-time. Economically, substituting part of the energy consumption with PV can reduce operational costs, especially for fuel [6], which is the main cost in gas-based power plants. In the long term, using renewable solar energy with an almost zero marginal cost will improve the economics of the hybrid power generation system.

From an environmental perspective, the integration of PV power plants reduces greenhouse gas emissions due to the decreased use of fossil fuels [4]. As a result, this system not only improves technical and economic efficiency but also helps in the decarbonization of the energy sector, particularly for electricity systems in remote or island areas such as Bawean. Moreover, the implementation of this hybrid PLTMG PV system demonstrates the possibility of replication in comparable electricity systems in Indonesia. Since island regions have limitations in primary energy supply, this method is relevant as a solution to enhance system reliability and efficiency while promoting the use of renewable energy.

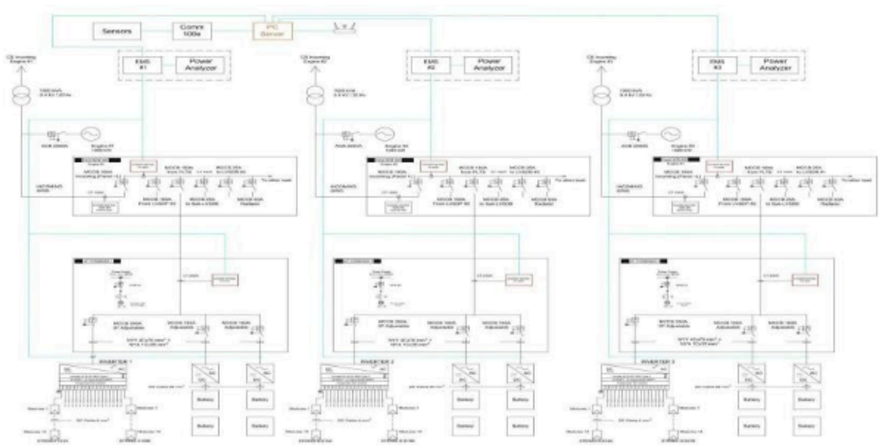

Fig. 3. Bawean solar system

3.2 Analysis of PLTMG's Own Usage Load

Table 1
Composition of self-use load (Auxiliary Load) in PLTMG

NO	Equipment	Power per Unit (kW)	Quantity	Total Power (kW)
1	Motor LT	1.6	3	4.8
2	Heater Engine	9		
3	Preheating Pump	0.17	3	0,51
4	Trio Power Supply	9	3	27
5	Intake Fan	5.5	6	33
6	AC Panel	0.27	3	0,81
7	Rectify	0.4	1	0,4
8	Motor Fan Radiator	3.1	18	55,8

9	Office Building	4	1	4
10	Heater Generator	0.2	3	0,6
11	Unit Description	4	5	20
12	Heater NGR	0.1	2	0.2
13	Heater SDB	0.1	3	0.3

According to the data, the self-consumption load in the PLTMG consists of various operational support equipment, such as motors, pumps, cooling systems, and compressors. The analysis results show that the total internal load is 643.42 kW, coming from all equipment operating within the power generation system [14,15]. Overall, the load distribution shows that not all equipment contributes equally. The DPS compressor is the component that contributes the most to the total internal load, thus playing a dominant role in determining the internal energy consumption level of the power plant. Other equipment, such as radiator motors and intake fans, also contribute significantly, although not as much as the compressor [3,13]. The results show that the focus of efficiency improvement strategies should be on the equipment that consumes the most energy. This is because improvements in this area will have a greater impact on overall internal load reduction.

Fig. 4. Self-discharging load composition graph

3.3 Percentage of Self-Use to Generation Capacity

According to the analysis results, about 21.45% of the total power plant capacity is used to meet internal needs. Using Equation (1), this value is calculated by comparing the installed capacity of the PLTMG with the total auxiliary load [8,16]. This percentage indicates that the operation of the power plant itself consumes most of the energy produced, rather than being distributed to external systems.

Therefore, one of the main opportunities to improve overall system efficiency is to reduce internal load.

3.4 Power and Energy Potential of Solar Power and Energy

According to the available data, the PV system can generate up to 120 kW of power. Considering daily operating hours, the energy produced reaches about 720 kilowatt-hours per day, or 21,600 kilowatt-hours per month [4], using Equation (2), which links power and operating time. These results indicate that the PV system has a fairly large capacity to meet internal energy needs, especially under normal operating conditions with sufficient solar radiation.

3.5 Percentage of Solar Power Plant Substitution to Internal Load

According to the analysis results, PV systems can replace approximately 18.65% of the total internal load. This value is obtained by comparing the power generated by the PV system with the total auxiliary load, as shown in Equation (3). This contribution cannot fully meet internal needs, but it is substantial enough to reduce dependence on the main generation [17]. This indicates that the integration of renewable energy can be a good way to reduce internal energy consumption.

3.6 Implications for PLTMG Operation Efficiency

After the contribution of the solar power plant (PLTS), the gas turbine power plant (PLTMG) still has to meet an internal load of 523.42 kW. This is the amount obtained from the difference between the total internal load and the power that can be supplied by the PLTS. With a heat rate value of 9000 kJ/kWh and energy produced by the PLTS of 21,600 kWh per month, the fuel energy requirement is greatly reduced [6,18]. These results indicate that the PLTS can lower fuel consumption at the PLTMG. This enhances energy efficiency and the overall performance of the power plant.

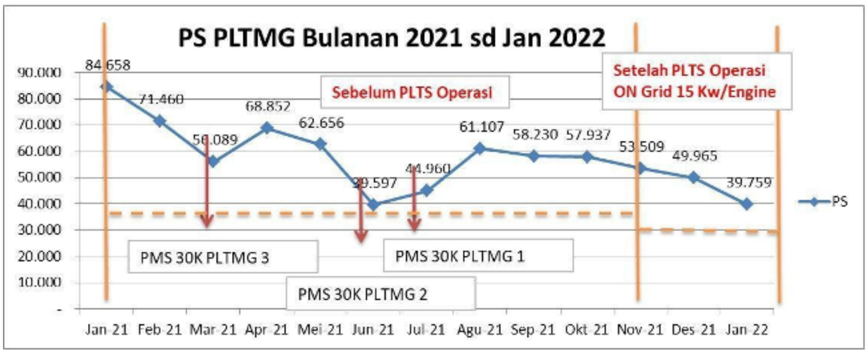

Fig. 5. Comparison chart before and after solar PV

Note: As a data source, the image still uses Indonesian, like the company's original documents.

3.7 Critical Review of Operational Constraints

Although solar PV has a positive impact on increasing energy availability and reducing dependence on conventional energy sources, the system still experiences various operational problems, such as overshoot and hunting caused by unstable controls. This situation shows that the implementation of solar power plants not only requires adequate power capacity, but also requires the quality of a control system that is reliable and responsive to changes in load and variations in energy sources [19,20].

The overshoot phenomenon can make the voltage or frequency in the system exceed the safe limit, while hunting indicates the presence of repeated oscillations that can accelerate tool damage and reduce system reliability. These issues usually arise due to poor regulation of control parameters, delays in system response, and lack of coordination between components in the power system.

Therefore, there needs to be an effort to improve the performance of the Energy Management System (EMS) in order to manage power distribution in a smarter and more adaptive way [6]. The application of variable setpoint settings is important to adjust to real-time operational conditions, especially when facing changes in output from solar power plants due to variations in sunlight. In addition, the protection system must also be improved to be able to respond quickly and appropriately to disturbances without disturbing the overall stability of the system.

Thus, the optimization of solar power plant integration is not only aimed at generating capacity, but also includes strengthening control strategies, improving the capabilities of the energy management system, and synchronizing the protection system to ensure stable, efficient, and reliable system operation.

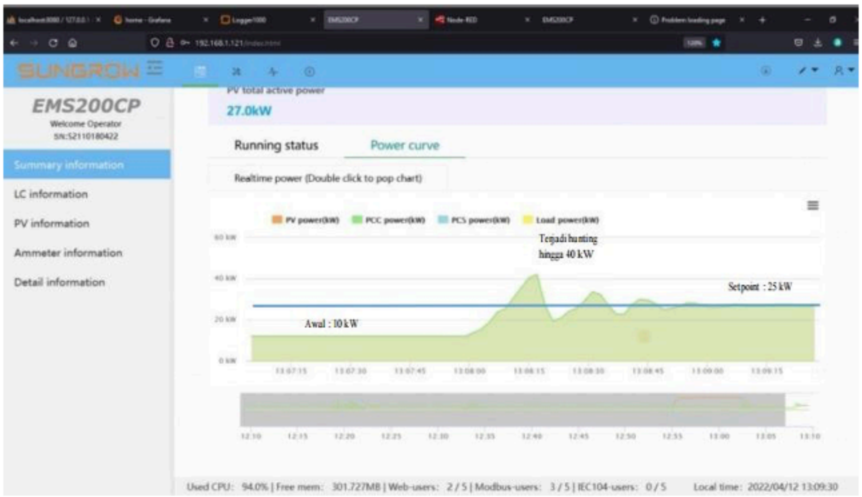

Fig. 6. Solar energy graph

4. Conclusions

Based on data analysis and processing, it can be concluded that the total internal usage load of the Bawean PLTMG reaches 643.42 kW. When compared to the 3 MW generation capacity, this figure is equivalent to 21.45% of the total generating capacity. This shows that the proportion of energy used for the internal needs of the plant is relatively large and has a significant impact on operational efficiency.

By design, the Bawean solar power system is indeed directed to provide auxiliary power for PLTMG engines through EMS. Referring to existing operational data, solar power plants are able to produce power in the range of 100–120 kW. Considering 120 kW as effective power used for 6 hours every day, the energy that can be used to replace the internal load reaches 720 kWh per day or 21. 600 kWh per month.

This contribution is equivalent to 18.65% of the total internal usage load. Thus, it can be seen that solar power plants are able to reduce the dependence of internal loads on supply from solar power plants, although they are not yet fully able to meet all additional load needs. The immediate impact of this situation is the increase in clean energy that can be used by the system and the potential savings on fuel.

However, optimizing the use of solar power plants depends not only on its ability to generate power, but also on control stability. The RCFA document noted overshoot and hunting issues indicating that EMS adjustments and protection settings still needed to be improved. Therefore, increasing plant efficiency through the integration of solar power plants will be better if it is followed by improving the control system and operational coordination between solar power plants, batteries, and solar power plants.

Acknowledgement

This publication was developed as a formal deliverable of the Internship Program facilitated by the Power Plant Engineering Technology Faculty of Vocational Studies at the State University of Malang. We thank the institution for providing the opportunity to integrate industrial experience with academic research.

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