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Outage Management and Reliability Analysis of Gas Engine Units in an Isolated Power System: A Case Study of PLTMG Bawean

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ABSTRACT

The Bawean Gas Engine Power Plant (PLTMG) is one of the power plants operating on an isolated electrical system to meet the electricity energy needs on Bawean Island. This power plant began operations in 2014 and uses three Jenbacher gas engine units with a capacity of 1 MW each, resulting in a total installed capacity of 3 MW. The generators used have an output voltage of 400 V with a frequency of 50 Hz and a power factor of 0.8. the reliability of the power plant's operation is greaty influenced by effective outage management, especially during planned maintenance activities. This study aims to analyse outage management on the gas engine unit at PLTMG Bawean by reviewing the application of maintenance intervals used in the power plant's operational system. The research method employed is a field study with the collection of operational data and engine maintenance documents. The maintenance system is based on engine operating hour intervals, namely PMS 2,000 hours, 4,000 hours, 8,000 hours, 12,000 hours, 14,000 hours, 18,000 hours, 22,000 hours, 24,000 hours, 28,000 hours, 32,000 hours, 34,000 hours, 38,000 hours, 42,000 hours, 44,000 hours, 48,000 hours, 52,000 hours, 54,000 hours, 58,000 hours with an estimated oitage of 1 day. Additionally, there are PMS 10,000 hours and 50,000 hours with an estimated outage of around 10 days, PMS 20,000 hours and 4,000 hours with an estimated of 14 days, and PMS 30,000 hours and 60,000 hours with an estimated outage of around 30 days. The engine operates at a speed of 1,500 rpm with a compression ratio 12:1 and a gas fuel pressure ranging from 0.08-0.2 bar. The inspection result show that the cylinder head components are in good conditions, the piston and liner are experiencing normal wear, the turbocharger does not show abnormal vibrations, and no leaks were found in the gas train system. In addition, the condition of the spark plug and valve clearance is normal. The research result show that the implementation of outage management thru a structured Preventive Maintenance Schedule (PMS) can maintain engine performance and improve the reliability of power plant operations in supporting the continuity of electricity supply in the isolated electrical system on Bawean Island.

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1. Introduction

Electricity is a primary necessity in supporting community activites, whether in the household sector, industry, or public services. The availability of a reliable electricity supply is an important factor in supporting the development and economic growth of a region [1]. In island regions or areas not connected to the main electricity grid, local power plants become the primary source of electricity supply. One type of power plant that is widely used in isolated electricity systems is the Gas Engine Power Plant (PLTMG) because it has relatively high efficiency, quick start-up time, and lower emissions compared to oil-fueled power plant [2].

PLTMG Bawean is a power plant that operates in an isolated electrical system on Bawean Island. This power plant began operating in 2014 and uses three Jenbacher gas engine units with a capacity of 1 MW each, resulting in a total plant capacity of 3 MW. The generators used have an output voltage of 400 V with a frequency of 50 Hz and a power factor of 0.8. as the main power plant in an isolated electrical system, PLTMG Bawean plays an important role in maintaining the continuity of electricity supply for the community on Bawean Island. Therefore, the reliability of the power plant's operation must be maintained to ensure it operates optimally and minimizes disruption that could lead to a decrease in the plant's performance [3].

One of the factors that affect the reliability of power plant operations is the management of outages or the condition where the power plant unit cannot operate due to maintenance activities or disturbances. Outages can be planned (planned outage) or unplanned (forced outage) [4]. In gas engine-based power plants, planned maintenance activities are generally carried out thru the implementation of a Preventive Maintenance Schedule (PMS) conducted periodically based on machine operating hours. A planned and systematic maintenance strategy can enhance equipment reliability and minimize plant downtime [4].

At the Bawean Gas Engine Power Plant, the gas engine maintenance system is carried out based on the machine's operating hour intervals, covering various stages of PMS from PMS 2,000 hours to PMS 60,000 hours. Each maintenance interval has different types of work and outage durations, ranging from minor maintenance with relatively short durations to major overhauls that require longer periods. Overhaul and periodic maintenance activities on gas engines are also known to improve mavhine operation efficiency and extend the operational lifespan of the power plant [5].

Based on this background, this study aims to analyze outage management on gas engine units at PLTMG Bawean based on the implementation of the Preventive Maintenance Schedule (PMS). This analysis is expected to prvide an overview of outage management in gas engine maintenance activities and its contribution to improving the operational reliability of the power plant in an isolated electrical system.

This study focuses on analyzing outage management based on actual operational disturbance data at PLTMG Bawean during 2025. The analysis emphasizes outage characteristics, causes of disturbances, duration of outages, and the amount of lost electrical energy to evaluate their impact on the operational reliability of the power plant in an isolated electrical system.

2. Theoretical Framework

2.1 Gas Turbine Power Plant (PLTMG)

Gas Engine Power Plant (PLTMG) is a power plant that uses an internal combustion engine fueled by gas to generate electrical energy. In this system, the chemical energy from the gas fuel is converted into mechanical energy through the combustion process in the engine cylinder, and then this mechanical energy is used to rotate the generator, thereby producing electrical energy [6]. Gas turbine power plants are widely used because they have relatively high efficiency and a relatively quick start-up time compared to several other types of power plants.

Fig 1. Gas engine at PLTMG Bawean [7]

PLTMG has several advantages compared to other types of power plants, including relatively fast start-up times, quite high efficiency, and flexibility in load operation [6]. Therefore, PLTMG is often used as a power plant in medium-scale electrical systems or as a supporting power plant in larger electrical systems. The energy generation process in a gas engine power plant (PLTMG) involves several main systems, namely:

- Gas fuel system
- Combustion air system
- Engine cooling system
- Lubrication system
- Electricity generation system (generator)

The flow of the electricity generation process in a gas engine power plant (PLTMG) can be seen in Fig 2.

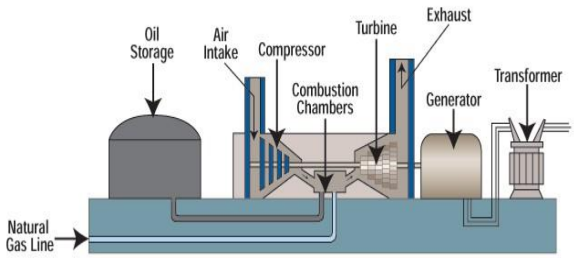

Fig. 2. Diagram of the gas engine power plant system [8]

In the picture, it can be seen that the gas fuel is channeled to the gas engine thru a pressure regulation and safety system. Next, the gas is burned inside the engine, producing mechanical energy used to drive the generator [9].

2.2 Fuel System

The gas fuel system is one of the important systems in the operation of a gas engine power plant (PLTMG) because it functions to deliver gas flow rates that meet the operational needs of the engine.

In PLTMG operation, natural gas from the supply source cannot be directly fed into the engine. The gas must first pass through a series of control and safety components to ensure that the gas entering the combustion chamber is clean, stable in pressure, and safe [10]. An unstable gas supply can cause imperfect combustion, engine performance degradation, and even trigger engine protection trips [11].

The gas fuel system generally consist of several main components that work as an integrated control and protection system before the gas enters the engine. These components are presented in Table 1.

Table 1
Main components of the gas fuel system

Component	Value
Filter Gas	Filtering particles or impurities from the gas
Regulator Pressure	Regulating gas pressure to meet the machine's needs
Valve Gas	Controlling the flow of gas to the machine
Train Gas	Gas flow safety and control system
Gas Distribution Pipe	Delivering gas to the machine unit

The gas train system plays a crucial role as a safety device in the fuel system. It is designed to automatically shut off the gas supply when abnormal conditions occur, such as pressure drops, overpressure, or detection of unsafe operating parameters. This safety mechanism is essential to prevent combustion failure and protect the engine from potential damage.

Proper operation of the fuel system ensures stable combustion inside the engine cylinder, which directly affects the mechanical energy produced to drive the generator and ultimately influences the reliability of electrical energy production in the PLTMG system.

2.3 Combustion Air System

The combustion air system functions to provide the air needed in the gas fuel combustion process within the engine. The air that enters the engine will be mixed with the gas fuel, forming a mixture that can ignite in the combustion chamber.

The combustion air in a gas engine power plant (PLTMG) is usually supplied thru several main components such as the air filter, turbocharger, and intake manifold [12]. The air filter functions to filter the air before it enters the engine, while the turbocharger serves to increase the air pressure so that the amount of air entering the combustion process can proceed more efficiently. The component of the combustion air system are shown in Table 2.

Table 2
Components of the combustion air system

Components	Functions
Air Filter	Filtering the air entering the engine
Turbocharger	Increasing the combustion air pressure
Intake Manifold	Supplying air to the engine cylinder

2.4 Electric Power Generation System

The mechanical energy produced by the gas engine is used to rotate the generator, thereby generating electrical energy. The generator operates based on the principle of electromagnetic induction, where a change in the magnetic field around a conductor will generate electrical voltage.

The electricity generation system in a gas engine power plant (PLTMG) consist of several main components, namely:

- Generator
- Generator excitation system
- Generator protection system
- Transformer

The generator produces electrical energy, which is then transmitted thru a transformer to the electrical energy, which is then transmitted thru a transformer to the electrical distribution system [13]. The relationship between the generator and the electrical distribution system can be seen in Fig 4.

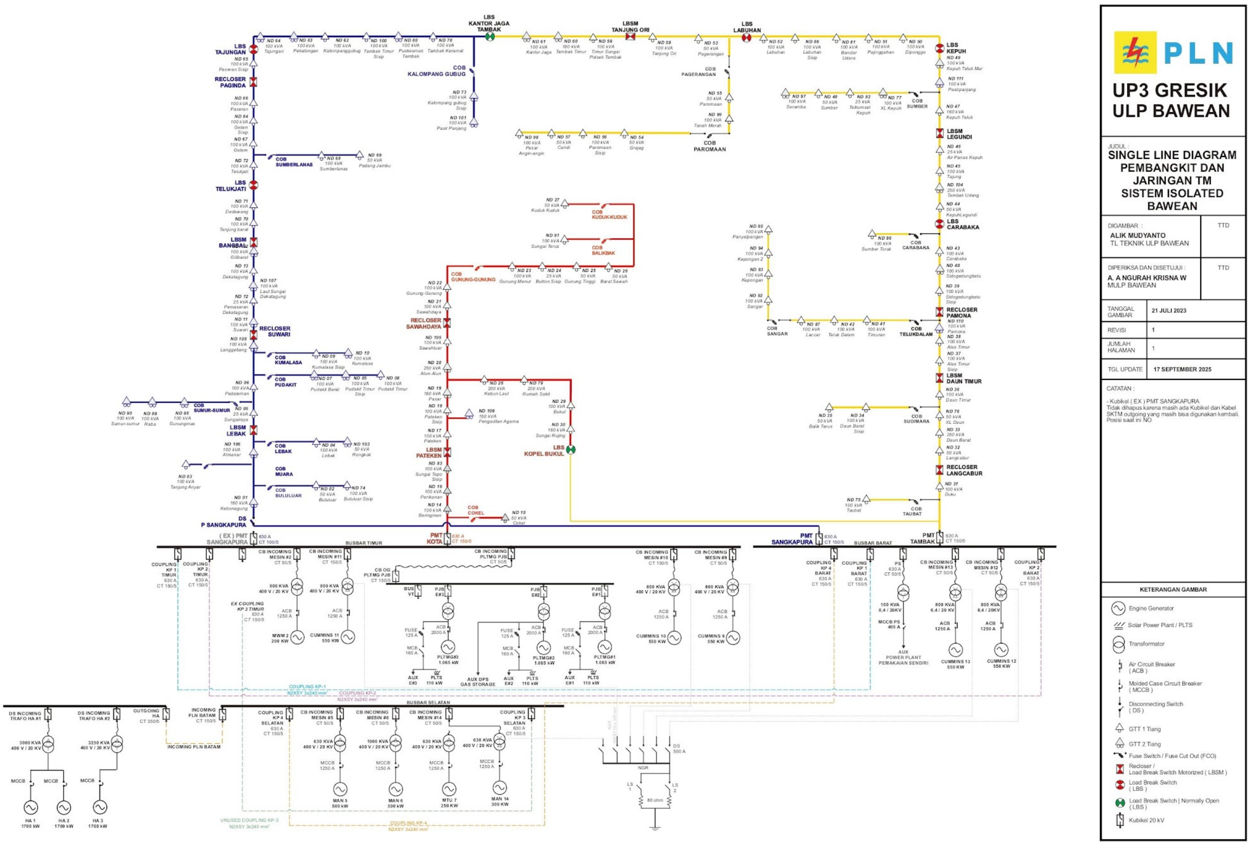

Fig. 4. Single line diagram of the generation system [14]

The single line diagram shows the relationship between the generator, transformer, and the electrical distribution network in the generation system.

2.5 Power Plant operational Disruption (Outage)

In power plant operations, an outage is a condition when the generating unit cannot operate normally, thus it cannot produce electrical energy. Outages can occur due to various factors such as equipment malfunctions, network system disturbances, or maintenance activities. In general, outages at power plants can be classifield into several types as shown in Table 3.

Table 3
Types of outages at power plants

Types of Outages	Explanation
Forced Outage	Unplanned disruptions causing the unit to stop operating
Maintenance Outage	Operation shutdown for maintenance acticites
Planned Outage	Previously scheduled operation shutdown

Forced outage is one of the important indicators in assessing the reliability of power plant operations because this disruption occurs unexpectedly and can lead to a loss of electricity production [15,16].

2.6 Cause of Disturbances in Power Plants

Disturbances in power plants can be caused by varios factors both from within the power plant system and from outside the power plant system.

Internal factors are usually related to equipment damage, generators, or other supporting systems. Meanwhile, external factors can originate from disturbances in the electrical grid system, such as transmission disturbances, distribution disturbances, or protection system disturbances [17]. The classification of disturbance causes in power plants can be seen in Table 4.

Table 4
Classification of disturbance cause

Category	Example of Disturbance
Machine System	Spark plug damage, cooling disturbance
Generator System	Excitation system disturbance
Network System	Feeder trip, transmission disturbance
Protection System	Trip due to electrical protection

2.7 Energy Loss Due to Disturbance

When a disturbance occurs in the power plant, the generating unit cannot produce electrical energy during the disturbance period. This condition causes a loss of electricity production, which is usually expressed in megawatt-hours (MWh) [18,19].

The amount of lost electrical energy is influenced by several factors, including the duration of the disturbance, the capacity of the power plant, and the operational load at the time of the disturbance. The longer the duration of the disturbance, the greater the amount of electrical energy that cannot be produced by the power plant.

3. Methodology

3.1 Research Method

This study uses a descriptive analysis method based on operational disturbance (outage) data of the generating units at the Gas Engine Power Plant (PLTMG) Bawean. The descriptive method is used to describe the characteristics of operational disturbances, identify the causes of outages, and evaluate their impact on the reliability of power plant operations [20]. The stages of the data analysis process carried out in this study are illustrated in Fig 5.

The flowchart shows the sequence of data analysis starting from data collection, outage classification, identification of disturbance causes, calculation of disturbance duration, calculation of lost electrical energy, and evaluation of the impact of disturbances on power plant operations.

3.2 Location and Time of Research

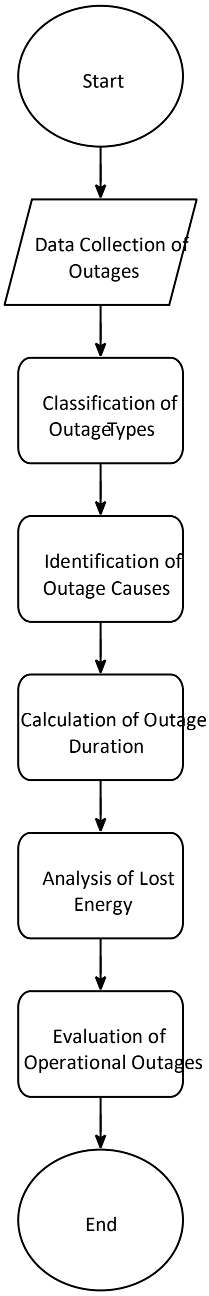

Fig. 5. Research data analysis flow diagram

This research was conducted on the Gas Engine Power Plant (PLTMG) Bawean system, which is part of the electrical system of Bawean Island. The PLTMG Bawean serves as one of the main sources of electricity generation, supplying the local electrical system's energy needs. Operation disturbance data is used to analyze the causes of disturbances and their impact on the reliability of power plant operations.

The research was conducted during the fieldwork (internship) activities using operational data obtained from the power plant's operation and maintenance unit. The data used are the operational disturbance data of the power plant unit during the period from January to December 2025.

3.3 Types and Sources of Data

The data used in this research are secondary data obtained from power plant operation records and operational activity documentation during the intership. The data used includes:

1. Operation disturbance data of the power generation unit
2. Start and end times of the disturbance
3. Type of outage that occurred
4. System load at the time of the disturbance
5. Duration of the disturbance
6. Electric energy lost due to the disturbance
7. Cause code

The disturbance data parameters used in the research are shown in Table 5.

Table 5
Power generation disturbance data parameters

Parameter	Description
Unit	Generating unit that experienced a disturbance
Outage start time	Date and time of the disturbance
Outage end time	Date and time the disturbance was resolved
Outage type	Category of the generating unit disturbance
Load during outage	Load operation of the generating unit during the disturbance
Outage duration	Duration of the disturbance
Lost energy	Electrical energy that could not be produced
Cause code	Cause code of the disturbance

The disturbance data is used to analyse the operational disturbance characteristic of the PLTMG power generation unit.

3.4 Data Collection Method

The data collection method for this research is carried out thru several stages, namely:

3.4.1 Field study

The field study was conducted by directly observing the operation system of the power plant and the operational process of the gas turbine unit at PLTMG Bawean. This observation aims to understand the working system of the power plant and the main components involved in the electricity generation process.

3.4.2 Documentation of operational data

Data collection is carried out by gathering operational data from the power plant, which includes unit disturbance data, outage data, and operational records documented in the power plant's operational recording system. The obtained data is then compiled and processed to obtain information regarding the characteristics of disturbances occurring in the power plant unit.

3.4.3 Literature study

The literature study is conducted by examining various references related to power generation systems, power plant operations, and disturbance analysis in power generation systems [15]. The references used include textbooks, scientific journals, and power plant operation manuals. According to Wood and Wollenberg [9], operational data analysis can be used to evaluate the reliability level of the plant and identify the causes of disturbances that occur during operation.

3.5 Classification of Outage Types

Operational disturbances are classified into:

Table 6
Outage type classification

Type of Outage	Description
Forced Outage (FO)	Unplanned disruption causing the unit to stop operating
Maintenance Outage (MO)	Unit shutdown for maintenance activities

Forced outages are sudden disturbances that prevent the generating unit from producing electricity.

3.6 Calculation of Outage Duration

Outage duration is the length of time a generating unit cannot operate due to a disturbance. The duration of the disturbance is calculated based on the difference between the start time of the disturbance and the end time of the disturbance. The equation used to calculate the duration of the disturbances is as follows:

$$\text{Duration Disturbance (hours)} = \text{End Time} - \text{Start time}$$

The duration of the disturbance is usually expressed in hours.

3.7 Calculation of Lost energy

Lost energy is the electrical energy that cannot be produced by the power plant due to operational disturbances. Lost energy is calculated based on the operational load of the generating unit and the duration of the disturbance that occurs. The equation for lost energy can be expressed as follows:

$$\text{Lost Energy (MWh)} = \text{Operating Load (MW)} \times \text{Outage Duration (Hours)}$$

The value of lost energy is used to determine the impact of disruptions on electricity production at the power plant.

3.8 Research Variables

The variables used in this research are parameters related to the characteristic of power plant operation disturbances.

Table 7
Research variables

Variable	Unit	Description
Duration of disturbance	hours	Duration of unit downtime
Load during disturbance	MW	System load when the disturbance occurs
Lost energy	MWh	Energy that cannot be produced
Type of outage	-	Power plant disturbance categories
Cause of disturbance	-	Factors causing the disturbance

3.9 Data Analysis Procedure

The data analysis steps include:
1. Collecting disturbance data from the generator unit
2. Categorizing disturbance based on outage type
3. Identifying disturbance causes based on cause code
4. Calculating the duration of disturbances that occur
5. Calculating the electrical energy lost due to disturbances
6. Evaluating the impact of disturbances on generator operation

The results are used describe the characteristics of operational disturbances at PLTMG Bawean.

4. Result and Discussion
4.1 Generator Disruption Data

This section highlights the main finding that outages in the generating units at PLTMG Bawean during 2025 were dominated by disturbances in the generator excitation system and the main components of the gas engine. These disturbance data serve as the basis for assessing the impact of outages on the reliability of the isolated system, as each disturbance directly reduces the power supply to the load.

Before looking at the detailed data, it is important to understand that the duration of outages and lost energy reflect the extent of the impact of disturbances on the electrical system. The longer the duration of the disturbance, the greater the amount of energy not supplied to system. Table 8 presents data on the time of occurrence duration of the disturbance, lost energy, and the cause of the disturbance for each unit.

Table 8
Disruption data of the Bawean gas turbine power plant unit

Unit	Date	Duration (hours)	Energy loss (MWh)	Cause of disruption
Unit 2	13 Jan 2025	8.22	8.75	Exciter generator
Unit 2	14 Jan 2025	7.97	8.48	Exciter generator
Unit 2	26 Jan 2025	0.18	0.20	Spark plug breakdown
Unit 2	24 sep 2025	1.98	2.11	Cooling system
Unit 3	15 Jan 2025	6.98	7.44	Exciter generator
Unit 3	15 Jan 2025	6.67	7.10	Exciter generator
Unit 3	30 Jan 2025	0.30	0.32	Spark plug breakdown

Unit 3	28 Feb 2025	1.40	1.49	Crankcase pressure
Unit 3	24 Apr 2025	7.12	7.58	Crankcase pressure

Based on Table 8, it is evident that the longest duration disturbances are mostly caused by the generator exciter, indicating that the excitation system has a significant impact on the continuity of generator operation in an isolated system.

4.2 Analysis of the Number of Disruption per Unit

To determine which unit experiences the most frequent disruptions, an analysis of the number of outage incidents for each unit is conducted. Fig 6 shows the graph of the number of disturbances per unit.

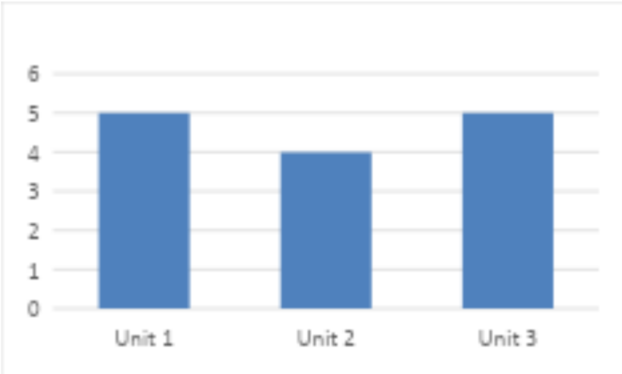

Fig. 6. Unit disruption quantity graph

From Fig 6, the main finding shows that Unit 3 experiences the most frequent disruptions. This directly impacts the reliability of the system because in an isolated system, the reduction of one generating unit will significantly decrease the system's power reserve.

4.3 Analysis of Disturbance Causes

After identifying the most frequently disrupted unit, the next analysis highlights the main causes of disruptions that trigger outages. Table 9 displays the distribution of disturbances that occurred during the observation period.

Table 9
Distribution of disturbance causes

Causes of Disturbances	Quantity
Exciter generator	4
Spark plug breakdown	2
Crankcase pressure	2
Cooling system	1

Fig 7, shows a visualization of the distribution of the causes of the disturbance.

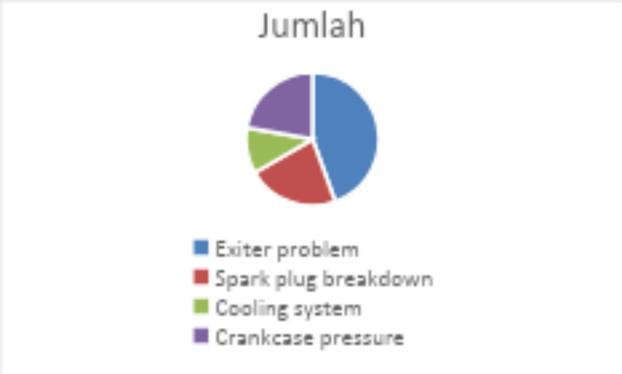

Fig. 7. Causes of disturbances chart

Based on Table 9 and Fig 7, the main finding is that the most dominant disturbances originate from the generator exciter. The excitation system plays a crucial role in maintaining the generator's voltage stability. Disturbances in this system not only cause unit trips but also have the potential to disrupt the overall voltage stability of the distribution system.

4.4 Analysis of Lost Electrical Energy

The outage that occurred not only affected the shutdown of the unit but also caused the electricity that was supposed to be produced to be lost. Table 10 shows the total energy lost in each unit due to disturbances.

Table 10
Lost energy due to disruptions

Unit	Lost Energy (MWh)
Unit 1	10.00
Unit 2	19.54
Unit 3	23.93

Fig 8, shows the comparison of energy loss between units.

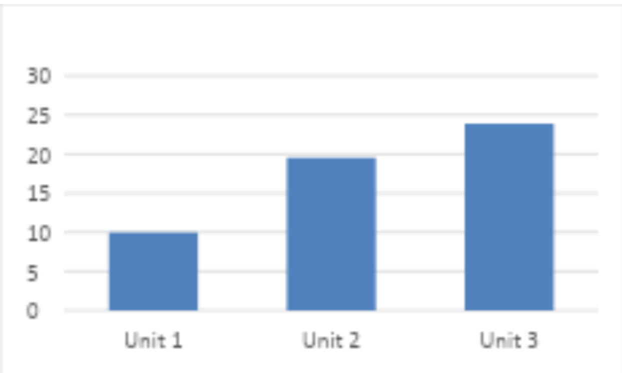

Fig. 8. Lost energy graph

From Table 10 and Fig 8, it is evident that Unit 3 has the highest energy loss. These findings are consistent with the high disturbance frequency on that unit. The impact on the isolated system is very significant because the lost energy means the system load must be reduced or borne by other units.

4.5 Power Plant Operating System

To understand the impact of disturbances on the system, it is necessary to understand the operational system of the power plant at PLTMG Bawean. Fig 9 shows the control panel in the Central Control Room (CCR) used to monitor important parameters such as generator power, voltage, frequency, and protection systems.

Fig. 9. CCR control panel PLTMG Bawean

Thru this system, operators can immediately detect disturbances and take protective actions. However, when the disturbance originates from the excitation system or internal engine components, the recovery process takes longer, resulting in an increased outage duration.

4.6 Power Plant Maintenance Activities

Maintenance activities are an important factor in reducing the occurrence of recurring outages. Fig 10, shows the Preventive Maintenance activities carried out periodically.

Fig. 10. Preventive maintenance activities

The findings in this section indicate that although PMS has been carried out, some issues such as spark plugs and crankcase pressure still persist, which suggests the need for increased inspection focus on these critical components.

4.7 Analysis of Gas Engine Malfunctions

Technical analysis shows that some disturbances originate from the internal components of the gas engine, particularly the spark plug and the crankcase ventilation system.The damaged spark plug causes the combustion process to be suboptimal, leading to the engine experiencing a trip protection. Meanwhile, the high crankcase pressure indicates a problem with the engine's ventilation system, wich could potentially damage internal components if not addressed promptly. The main finding in this section emphasizes that minor disturbances in engine components can develop into major outages that directly impact the reliability of isolated power generation systems.

5. Conclusion

This study shows that outages in gas engines in isolated power generation systems such as PLTMG Bawean have a significant impact on the reliability of power supply and the amount of energy lost during disturbance periods. The analysis results show that most outages are triggered by disturbance in the ignition system (spark plug), disturbances in the generator excitation system, and an increase in crankcase pressure that leads to a protective engine trip. The main findings of this study emphasize that the duration of outages is greatly influenced by the speed of identifying the cause of the disturbance and the effectiveness of the maintenance actions implemented in the field.

The calculation of disturbance duration and lost energy shows that each outage event not only reduces power availability in the isolated system but also directly impacts the continuity of electricity service to the load. From the evaluation result, the consistent application of preventive maintenance, the accuracy of inspection procedures, and the increased monitoring of critical components have proven capable of reducing the potential for recurring outages and improving the overall reliability of the power plant.

Thus, this research emphasizes that structured outage management, supported by technical analysis of the causes of disturbances and evaluation of lost energy, is key to maintaining the reliability of gas engine operations in isolated power generation systems. These findings can serve as a basis for improving maintenance strategies and disruption management in similar power plants.

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