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Electrical Power Generation and Load Distribution Analysis in the Power System of Production Operation III A at PT Petrokimia Gresik

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ABSTRACT

Electrical energy is essential for maintaining stable and continuous industrial operations. However, mismatches between power generation and load demand may reduce system reliability. This study analyzes the characteristics of electrical power generation and load distribution in the industrial power system at Production Operation IIIA of PT Petrokimia Gresik. The study utilizes actual operational data from steam turbine generators TG-65 and TG-66 and applies a mathematical model to evaluate total generated power, load demand, and power balance. The analysis focuses on the relationship between generation and load, as well as the distribution of electrical energy across production units. The results indicate that both generators operate in parallel with balanced load sharing and are capable of responding dynamically to load variations. The system predominantly operates under surplus power conditions, confirming that the available generation capacity is sufficient. Load distribution analysis shows that energy consumption is concentrated in high-demand units, particularly the PA Plant and AS Plant, while other units exhibit relatively stable and moderate consumption. In conclusion, the industrial power system demonstrates stable and reliable performance, supported by adequate generation capacity and effective load distribution, ensuring continuous operation under varying load conditions.

1. Introduction

Electrical energy is one of the main components in supporting the continuity of production processes in large-scale industries. Industrial power systems not only function as energy providers for various production equipment, but also play an important role in maintaining operational stability and overall industrial process efficiency. Industries with high energy demand generally operate internal power generation systems to ensure the continuity of electricity supply and improve the reliability of the power system. Recent studies indicate that the management of electrical energy distribution systems in industrial facilities requires proper monitoring of load characteristics and generation performance so that the system can operate stably and efficiently [1,2].

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In steam turbine-based power generation systems, the generator functions to convert mechanical energy from the turbine into electrical energy that can be used to meet the needs of the production process. The performance of the generator is highly influenced by loading conditions during operation. Variations in electrical load occurring in industrial distribution systems can affect generation efficiency, voltage stability, and the overall performance of the power system. Several studies indicate that changes in load profiles in power systems can cause power distribution imbalances and reduce the operational efficiency of power plants if not properly managed [3,4].

In addition, the balance between the power generated by the generator and the electrical load demand is an important factor in maintaining the stability of the power system. An imbalance between generation and load demand can cause various operational problems such as decreased power quality, voltage fluctuations, and increased energy losses in the distribution system. Analysis of power quality and load characteristics in industrial power systems becomes an important aspect in identifying potential disturbances and improving the reliability of the power system [5,6].

In modern industrial environments, electrical energy distribution systems generally serve various types of loads such as electric motors, pumps, compressors, and process control systems that have dynamic load characteristics. Load characteristics that change during the production process can cause significant variations in electrical energy consumption. Therefore, monitoring electrical energy generation and load distribution directly in the field becomes an important approach to accurately evaluate the performance of industrial power systems. Several studies also indicate that approaches based on actual operational data can provide a more representative description of the characteristics of industrial power systems compared to approaches based solely on simulations [7,13,14].

On the other hand, research on turbine-based energy generation systems shows that optimizing operational parameters such as steam pressure, steam temperature, and generator load distribution can improve energy generation efficiency and reduce energy losses in power generation systems. Energy and exergy analyses in power generation systems also show that improvements in system efficiency can be achieved through comprehensive evaluation of the performance of generation components, including turbines and generators [8-11]. In addition, the development of data-based methods in the management of industrial power systems is increasingly being used to improve operational efficiency and optimize electrical energy distribution in modern power generation systems [12,15].

Recent studies have also explored several advanced approaches in analyzing and optimizing industrial power systems, including load variation analysis, power quality improvement, field data-based evaluation, and machine learning techniques. These approaches provide a more comprehensive understanding of system performance, particularly in addressing dynamic load characteristics and improving the balance between power generation and consumption. In addition, thermodynamic-based methods such as exergy analysis have been widely used to evaluate and enhance the efficiency of power generation systems. A summary of recent research related to electrical power system analysis in industrial applications is presented in **Table 1.**

Table 1
Literature review of electrical power system analysis in industrial applications

References	Method	Research Focus	Key Results
[16]	Load variation analysis	Power plant efficiency under varying load	Load fluctuations significantly affect generation efficiency and performance
[17]	Power quality analysis	Industrial power distribution systems	Improves power quality and reduces disturbances in electrical systems
[18]	Field data analysis	Industrial energy system optimization	Provides accurate evaluation based on real operational data

[19]	Exergy analysis	Steam power plant performance	Enhances thermodynamic efficiency and reduces energy losses
[20]	Machine learning approach	Load forecasting in industrial power systems	Improves prediction accuracy and supports energy management

Although various studies have discussed power system analysis and energy generation performance, most of these studies still focus on utility-scale power plants or conventional power generation systems. Research that specifically analyzes the characteristics of electrical energy generation and load distribution in internal power generation systems within industrial facilities is still relatively limited, especially those using actual operational data from industrial generators. In fact, analysis based on field operational data is very important to understand the characteristics of industrial power systems more realistically. Based on these conditions, this study aims to analyze the characteristics of electrical energy generation and load distribution in the power system at Production Operation IIIA of PT Petrokimia Gresik by using operational data from generators TG-65 and TG-66. This analysis is conducted to evaluate the relationship between the electrical power generated by the generators and the electrical load demand in the production units, thereby providing an overview of the operational characteristics of the internal power generation system and its contribution to electrical energy management in industrial power systems.

2. Methodology

2.1 Research Flowchart

The research method used in this study is based on a systematic data analysis approach applied to industrial power systems, which includes the processes of processing, evaluating, and interpreting operational data obtained directly from the field. As shown in **Figure 1**, the analysis begins with the collection of primary data, including electrical power generation data from steam turbine generators TG-65 and TG-66, as well as electrical load data from various production units. The collected data are then processed to calculate the total power generation and the total electrical load distribution within the system. Furthermore, a power balance analysis is conducted to evaluate the relationship between generated power and load demand, in order to identify system stability, efficiency, and potential imbalances. The final stage involves analyzing the overall characteristics of power generation and load distribution based on the processed data, thereby providing a comprehensive understanding of the operational performance of the industrial power system.

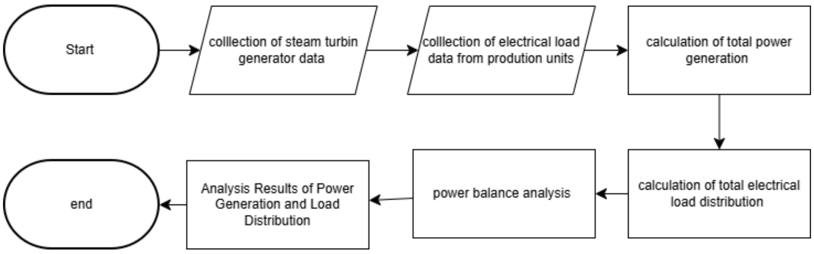

Fig. 1. Research flowchart

2.2 Steam Turbine Generator Specification

The industrial power system in Production Operation IIIA of PT Petrokimia Gresik is supplied by two steam turbine generator units, namely TG-65 and TG-66, which operate in parallel to meet the electrical energy demand of the production units. A steam turbine generator is a device that functions to convert the thermal energy of steam into mechanical energy in the turbine, which is then converted into electrical energy through a synchronous generator [21].

In steam turbine-based power generation systems, generator performance is strongly influenced by turbine operating conditions, steam pressure, and variations in electrical loads served by the industrial power system. Load variations in the generator can cause changes in generation efficiency and the overall operational performance of the power plant [22]. Therefore, understanding the specifications of the turbine generator is very important to determine the electricity generation capacity as well as the operational characteristics of the power system analyzed in this study.To provide an overview of the working principle of the steam turbine power generation system used in the industrial power system, the basic configuration of the gas-electric steam turbine system can be shown in **Figure 2.**

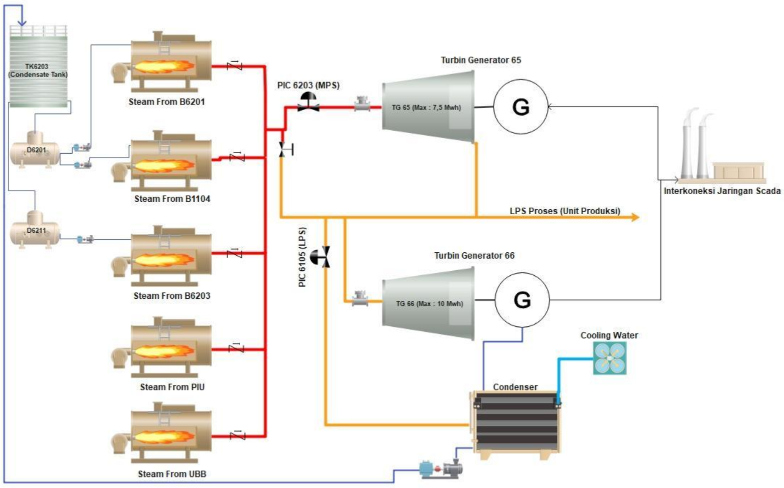

Fig. 2. Gas-electric steam turbine system

The main specifications of the generators used in this study are presented as a reference for understanding the operational characteristics of the steam turbine generators applied in the industrial power system. These specifications include key parameters such as generator type, rated output, and steam conditions, which are essential for evaluating the performance and capacity of each generator unit.

Table 2
Turbine generator specification

Parameter	TG-65	TG-66
Generator type	Steam Turbine Generator	Steam Turbine Generator
Rated output	8500 KW	11500 KW
Inlet pressure	34,5 kg/cm^2g	9,8 Kg/cm^2g
Outlet	10 Kg/cm^2g	Condensate

Based on the specifications presented in **Table 2**, it can be observed that the two steam turbine generators have different operational characteristics in terms of rated capacity and steam parameters, which directly influence their roles in supplying electrical energy to the industrial power system. The higher rated output of TG-66 indicates its capability to supply a larger portion of the electrical load compared to TG-65, while the differences in inlet and outlet steam conditions reflect variations in thermodynamic performance and energy conversion processes. By examining these parameters, it becomes possible to identify differences in operational capability between TG-65 and TG-66, particularly in terms of power generation capacity and thermodynamic conditions. These differences are important in determining how each generator responds to load variations and contributes to the overall power balance within the system. Furthermore, the parallel operation of both generators enables more flexible load sharing and enhances system reliability, particularly under dynamic operating conditions in industrial environments, thereby supporting further analysis related to power generation performance and load distribution within the system.

2.3 Electrical Load Distribution Characteristics

The electrical energy generated by generators TG-65 and TG-66 is subsequently distributed to various production units through the industrial power distribution system. This distribution system functions to deliver electrical energy from the generation source to loads located in various production plants. In industrial power systems, the characteristics of load distribution are strongly influenced by the type of production process taking place in each unit. Each production unit has a different level of electrical energy consumption; therefore, the distribution of electrical loads in industrial power systems is dynamic and depends on the operating conditions of the plant [23]. In the system analyzed in this study, electrical energy is distributed to several main production units, namely: SA Plant, PA Plant, CT Plant, UT Plant, AS Plant. To provide an overview of the configuration of the electrical power distribution system used in this study, the structure of the industrial power network is presented through a single line diagram in **Figure 3**.

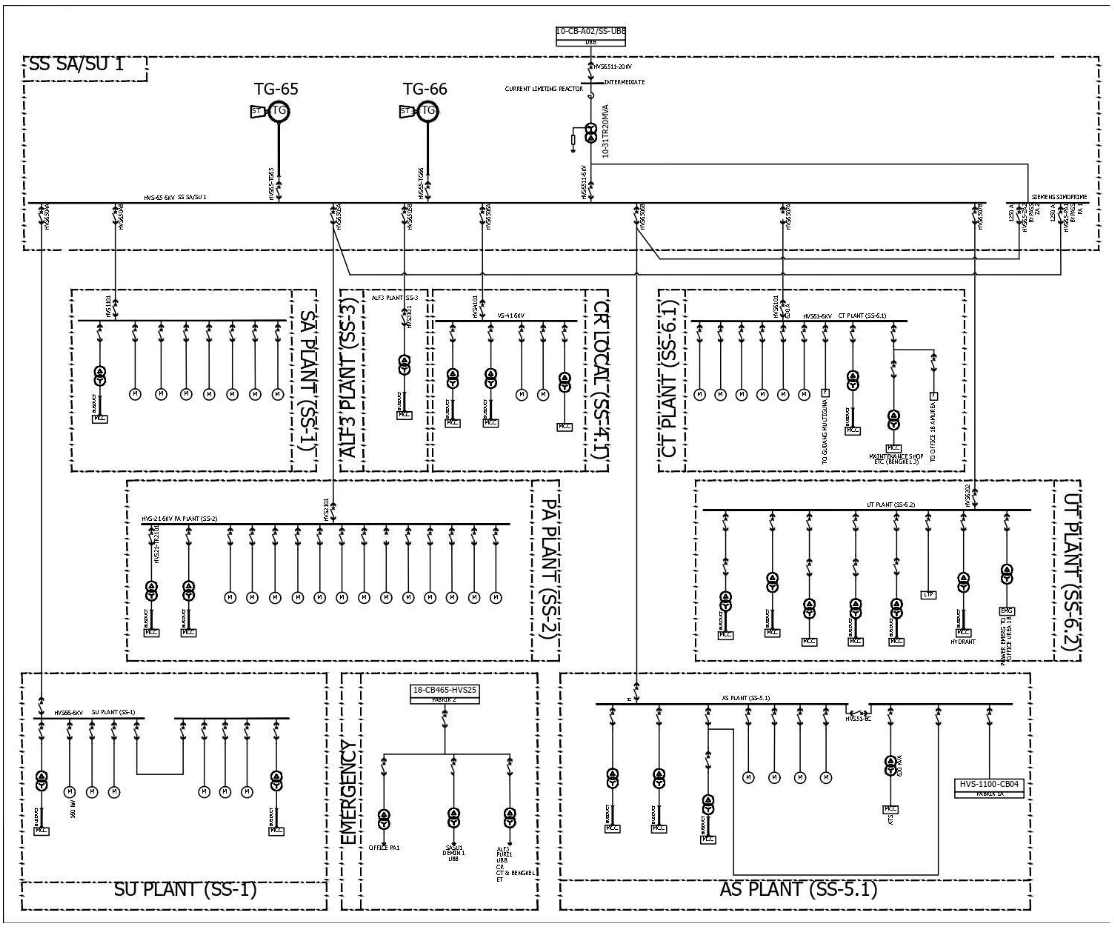

Fig. 3. Single line diagram of industrial power system

2.4 Mathematical Model

The analysis of power generation and electrical load distribution in the industrial power system is carried out using a simple mathematical model that describes the relationship between generator power generation and the total electrical load in the system. The total electrical power generation of the system is calculated as the sum of the power produced by generators TG-65 and TG-66, which can be expressed as:

The total generated power is determined using equation (1) [12,13]:

$$P_{total} = P_{TG65} + P_{TG66} \tag{1}$$

Where, P_{total}= total power generation of the system (MW), P_{TG65}= electrical power generated by generator TG 65 (MW),P_{TG66} = electrical power generated by generator TG-66 (MW).

Subsequently, the total electrical energy consumption in the system is calculated based on the sum of the power utilized by each production unit. The total load is expressed using equation (2) [1, 14]:

$$P_{load} = \sum_{i=1}^{n} Pi \tag{2}$$

Where P_{load} = total electrical load of the system (MW), P_i = electrical power at each production unit.
To determine the power balance in the industrial power system, the difference between the generated power and the load power is calculated. The power balance is evaluated using equation (3) [2, 7]:

$$\Delta P = P_{total} - P_{load} \text{ (MW)} \tag{3}$$

The power balance value is used to evaluate whether the electrical power generated by generators TG-65 and TG-66 is sufficient to meet the electrical energy demand of all production units connected to the industrial power system.

3. Results

3.1 Steam Pressure and Power Generation Characteristics of TG-65 and TG-66

This section presents the relationship between steam pressure (represented by steam flow rate) and the electrical power generated by steam turbine generators TG-65 and TG-66 based on operational data during February 2026. Steam turbine generators produce electrical energy by utilizing the thermal energy of high-pressure steam, which is converted into mechanical energy and subsequently into electrical energy through a generator. Theoretically, turbine power can be expressed as:
The turbine power is expressed using equation (4) [9, 13]:

$$P = \dot{m}(h_1 - h_2)\mu \tag{4}$$

Where the output power is influenced by the steam flow rate, the enthalpy difference, and the system efficiency. In this study, the parameter used is the steam mass flow rate (ton/hour) as a representation of steam pressure conditions. Based on the operational data presented in **Table 3**, it can be observed that there are differences in the characteristics of TG-65 and TG-66 in terms of steam flow rate and generated power. In this section, the analysis of total generated power from TG-65 and TG-66 refers to the mathematical model presented in **equation (1)**, where the total power is obtained from the combination of both generators operating in parallel.

Table 3
Steam pressure and power generation of TG-65 and TG-66

Turbin Generator	Steam flow (ton/hour)	Power Output (MW)
TG 65	± 90.5	± 5.6
TG 66	± 24.2	± 3.5

3.1.1 Analysis of differences between TG-65 and TG-66

Based on the operational data obtained during the February 2026 period, TG-65 and TG-66 exhibit identical operating characteristics, both in terms of generated power and steam flow rate utilized. There is no significant difference between the two generator units, where the power output and steam flow values in each operating period tend to be similar. This indicates that both generators operate in parallel with balanced load sharing. Mathematically, the difference in power and steam flow between TG-65 and TG-66 approaches zero, indicating that the generation control system is capable of distributing the load evenly and maintaining the operational stability of both generator units. This condition is consistent with the mathematical representation in **equation (1)** , where the total generated power is distributed proportionally between TG-65 and TG-66, resulting in a nearly equal contribution from both units.

3.1.2 Effect of steam pressure on power output

The analysis results indicate that the steam flow rate has a significant influence on the electrical power generated by both generators. In TG-65, when the steam flow increases to approximately 107.6 ton/hour, the generated power reaches a maximum of 7 MW, whereas at lower steam flow conditions, the generated power ranges from 3.8 to 4 MW. Meanwhile, in TG-66, an increase in steam flow from approximately 3.4 ton/hour to 30.2 ton/hour results in a rise in power from 2.5 MW to around 4.5 MW. This indicates a positive relationship between steam pressure and power output in both generator units.

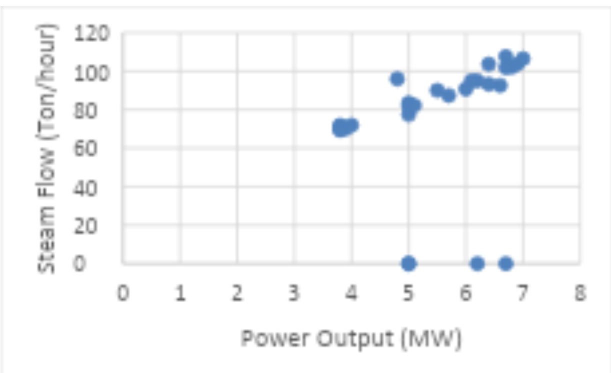

Fig. 4. Relationship between steam pressure and power output TG 65

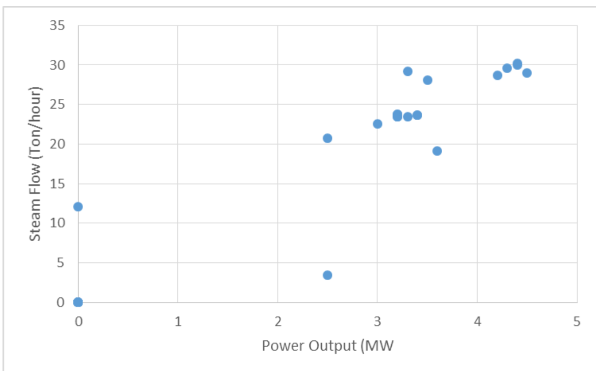

Fig. 5. Relationship between steam pressure and power output TG 66

Based on the graph of the relationship between steam flow and power output in **Figure 4 and 5**, it can be observed that both generators exhibit an increasing power trend as the steam flow increases, indicating a fairly strong positive correlation. In TG-65, this relationship tends to be nearly linear within the normal operating range, but begins to show a reduced rate of power increase as it approaches maximum capacity. A similar pattern is also observed in TG-66, where the power output tends to reach saturation around 4.5 MW. This phenomenon indicates the presence of an operating limit for each turbine, where additional steam flow no longer results in a significant increase in power output. However, this relationship is not entirely linear, as under certain conditions an increase in steam flow is not accompanied by a proportional increase in power, indicating the influence of other factors such as turbine efficiency, mechanical losses, and generator capacity limitations.

3.1.3 Generator operation stability analysis

The stability of generator operation can be observed from the fluctuations in the generated power during the observation period. TG-65 shows a relatively stable operating pattern with a power range between 3.8 MW and 7 MW. Although there are variations, this generator operates continuously throughout the month. In contrast, TG-66 exhibits more significant fluctuations, particularly at the beginning of the month when the generator was not operating (0 MW), as well as during several other shutdown periods. After entering normal operating conditions, TG-66 demonstrates stable power in the range of 3 to 4.5 MW. This difference indicates that TG-65 has a higher level of operational reliability compared to TG-66, which tends to experience non-continuous operation.

3.2 Electrical Power Distribution in Industrial Plants

The distribution of electrical energy plays a crucial role in ensuring that each production unit receives sufficient power to maintain continuous and stable operation. Based on the analyzed operational data, each plant unit exhibits different levels of electrical power consumption depending on the nature and intensity of its processes. The PA Plant is identified as the largest consumer of electrical energy, followed by the AS Plant. Both units dominate the overall load due to their involvement in energy-intensive industrial processes. Meanwhile, the CT Plant shows relatively stable consumption, while the UT Plant operates at a moderate level. In contrast, the SA Plant has the lowest electrical demand, indicating minimal contribution to the system. The total electrical load distributed across all plant units in this section is evaluated based on the mathematical model described in **equation (2)**, where the overall system load is obtained from the summation of individual unit loads.

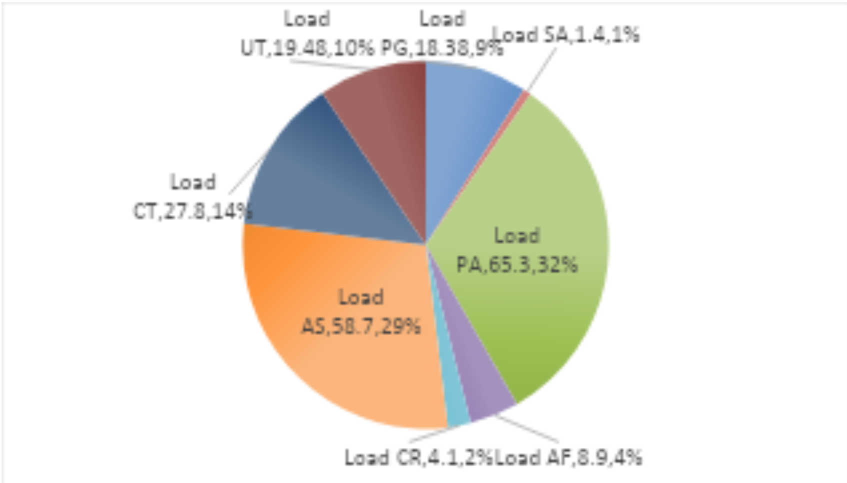

Fig. 6. Electrical load distribution of industrial plants

From the graphical representation shown in **Figure 6**, it can be clearly observed that the PA Plant has the highest average load, significantly exceeding other units. The AS Plant also contributes a substantial portion of the total load, making it the second dominant consumer. The CT Plant maintains a consistent intermediate load level, whereas the UT Plant operates at a slightly lower range. The SA Plant, on the other hand, shows a negligible contribution compared to other units. This distribution pattern indicates that electrical energy consumption within the industrial system is not evenly distributed, but rather concentrated in specific units with high operational demands. Units with intensive mechanical and thermal processes tend to require higher electrical power, while auxiliary and supporting units consume less energy. Overall, the analysis highlights that the stability and efficiency of the power distribution system heavily depend on the major load centers, particularly the PA and AS Plants, which dominate the electrical demand within the industrial network. This uneven distribution of load reflects how each unit contributes differently to the total electrical demand depending on its operational intensity.

3.3 Power Balance between Generation and Load

In industrial power systems, power balance is crucial to maintain operational stability. If the generated power is unable to meet the load demand, system disturbances may occur. Conversely, if the generated power exceeds the load demand, the system has a reserve margin that can enhance operational reliability. The evaluation of power balance in this section is based on the mathematical formulation presented in **equation (3)**, which defines the difference between total generated power and total load demand. The following graph presents a comparison between power generation and electrical load based on operational data:

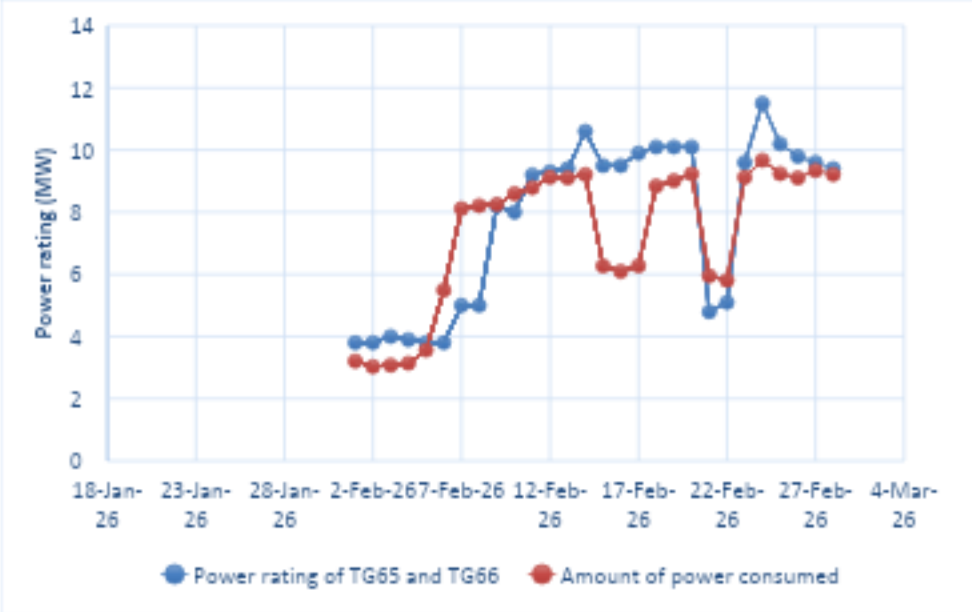

Fig. 7. Comparison between generated power and electrical load

From the graph, it can be observed that the power generation pattern (TG-65 and TG-66) generally follows the electrical load demand pattern. As shown in **Figure 7**, this indicates that the generator operation is adjusted in accordance with the system load requirements. In several periods, the generated power exceeds the electrical load, indicating a surplus power condition. However, there are also conditions where the difference between generation and load is relatively small, suggesting that the system operates close to its capacity limit. Overall, the power balance between generation and load in this industrial system is in a stable and safe condition, with a tendency toward power surplus. TG-65 and TG-66 are capable of adequately meeting the electrical energy demand of all plant units, while also providing a sufficient operating margin to maintain the continuity of the production process. These results indicate that the industrial power system has been designed and operated optimally. Nevertheless, monitoring of peak load conditions remains necessary to ensure long-term system reliability. The positive difference between generated power and load demand indicates a surplus condition, confirming that the system operates within a stable and reliable margin.

4. Conclusions

Based on the analysis conducted, it can be concluded that the steam turbine generator-based power system consisting of TG-65 and TG-66 at Production Operation IIIA of PT Petrokimia Gresik is generally capable of meeting the electrical energy demands of all production units. The generation pattern shows that both generators operate in parallel with relatively balanced load sharing and are able to respond dynamically to variations in electrical load. In addition, the power balance condition indicates a surplus in most operating periods, suggesting that the generation capacity is sufficient and provides an adequate reserve margin to maintain the stability and reliability of the industrial power system.

In terms of load distribution, electrical energy consumption is not evenly distributed among all plant units but is concentrated in high-energy-demand units such as the PA Plant and AS Plant, which serve as the main contributors to the overall system load. Meanwhile, supporting units such as the

CT Plant and UT Plant exhibit more stable and moderate consumption patterns, while the SA Plant contributes relatively minimal load. This distribution pattern indicates that energy consumption characteristics are strongly influenced by the type of production processes in each unit. Overall, the electrical power distribution system operates effectively and is capable of supporting industrial operations optimally, although monitoring of peak load conditions remains necessary to ensure long-term system reliability.

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