Jurnal Dinamis (*Scientific Journal of Mechanical Engineering*)
Journal homepage: https://talenta.usu.ac.id/dinamis/

Analysis of the Effect of Load Variation on Performance Gas Turbine Generator 1.1 at PLTGU UP Cilegon

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ARTICLE INFO
Article history:
Received November 12th 2024
Revised November 20th 2024
Accepted December 10th 2024
Available online December 11th 2024

E-ISSN: 2809-3410

How to cite:
Prayoga Dwi Cahyo Sutomo Putra, Hotdian Sinambela,Edy Susanto.“Analysis Of The Effect Of Load Variation On Performance Gas Turbine Generator 1.1 At PLTGU UP Cilegon.’’ Jurnal Dinamis *(Scientific Journal Of Mechanical Engineering)* Vol. 12 No 2, 87-96, December. 2024.

ABSTRACT
PT PLN Indonesia Power UP Cilegon is one of the steam and gas power plants that supplies additional power for western Java from the Java Bali system and supports the development of the western Java industrial area. But to fulfill this electricity supply there are still problems, especially in the addition of loads that greatly affect the performance of the gas turbine. The purpose of this study is to analyze and compare how much influence the load variation has on the performance of the gas turbine system and on the GTG thermal efficiency at PLTGU Cilegon unit 1.1 with load variations of 125 MW, 128 MW, 143 MW, and 190 MW. The method used is analysis of PLTGU operational logsheet data, specific calculations on gas turbines and calculation of GTG thermal efficiency. In the results of this study, an increase was obtained from each load variation. The highest performance value is obtained at a load of 190 MW. Load variations greatly affect gas turbine performance and thermal efficiency, where the greater the load, the higher the performance and efficiency of the gas turbine.
Keywords*: *Power plant system, variations load, thermal efficiency

ABSTRAK
PT PLN Indonesia Power UP Cilegon salah satu pembangkit listrik tenaga uap dan gas yang menyuplai tambahan daya untuk Jawa bagian barat dari sistem Jawa Bali dan mendukung perkembangan daerah industri Jawa bagian barat. Namun untuk melengkapi pasokan listrik ini masih terjadi permasalahan, terutama pada penambahan beban yang berdampak pada kinerja dari turbin gas. Tujuan penelitian ini ialah untuk menganalisa serta membandingkan seberapa besar pengaruh variasi beban terhadap unjuk kerja kinerja sistem turbin gas dan terhadap efisiensi *thermal* GTG di PLTGU Cilegon unit 1.1 dengan variasi pembebanan 125 MW, 128 MW, 143 MW, dan 190 MW. Metode yang digunakan yaitu analisa data *logsheet* operasional PLTGU, perhitungan secara spesifik pada turbin gas dan perhitungan efisiensi *thermal* GTG. Pada hasil penelitian ini didapatkan peningkatan hasil dari setiap variasi beban. Nilai unjuk kerja maksimum didapatkan pada beban 190 MW. Variasi beban sangat berpengaruh terhadap kinerja turbin gas dan efisiensi thermal, dimana semakin besar beban maka peforma dan efisiensi yang dihasilkan turbin gas semakin tinggi.
Kata kunci: Sistem PLTGU, Pembebanan, Efisiensi Termal

http://doi.org/10.32734/dinamis.v12i2.18830

1. Introduction

Nowadays, the need for energy, especially electric power, is very important. With the development of technology comes an increasing demand for electrical energy.[1] Therefore, generators often have to adjust their electricity production to match consumer demand. In response to changes in load variations, various aspects such as fuel supply, air supply for combustion, and exhaust gas discharge will also change automatically. Changes in the generation workload will also affect its operational efficiency.[2] In generation, varying loads are common. Variations in loading greatly affect the performance of generation system components.[3]

Through this research, the author collected data for 2 months from March to May 2024, and obtained an average load variation of 125 MW, 128 MW, 143 MW, and 190 MW. The load variation is determined because the Cilegon PLTGU is minimizing operating costs so that the fuel supply is limited, and then a load change is determined by PT PLN Persero load regulation center (P2B).

Table 1.1 Value of Load Variation on The Generator

No	Load Variation on Generator (MW)
1.	125
2.	128
3.	143
4.	190

The combination of a gas-fired power plant and a steam power plant results in a combined cycle power plant. Combined cycle power generation is the term used to describe the current cycle. The Rankine and Brayton cycles are combined to create a combined cycle. A frequently used combination is the 2-2-1 combination such as 2 Gas Turbine Generators (GTG), 2 Heat Recovery Steam Generators (HRSG) and 1 Steam Turbine Generator (STG). [4]

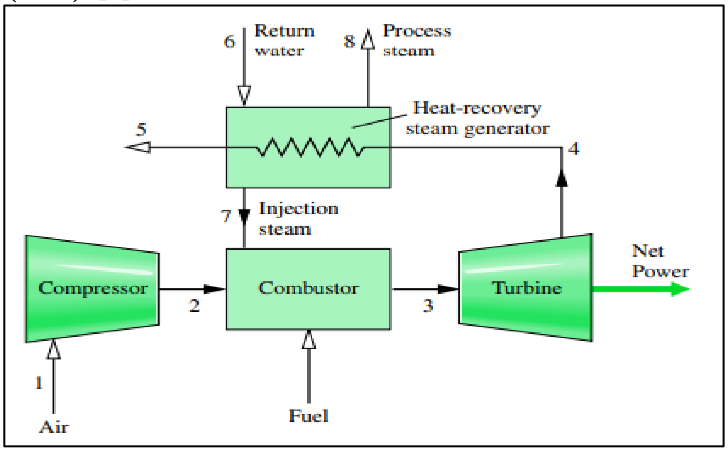


Figure 1.1 PLTGU Cycle

The Brayton cycle is the best thermodynamic model for gas turbines, turbine engine manufacturers today choose to use it when analyzing the performance of their gas turbines. The Brayton cycle entails heat release at constant pressure after isentropic compression. Each condition in the Brayton cycle can be examined as shown figure 1.2 [5].

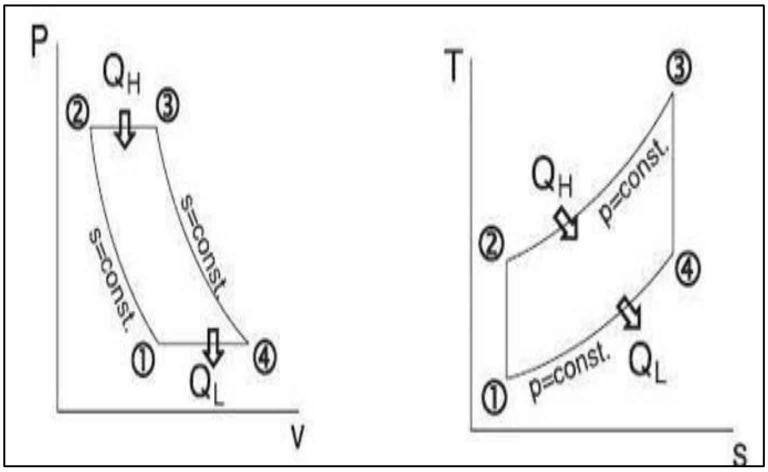


Figure 1.2 P-V and T-S Diagrams

The stages of the gas turbine work process are as follows:
From the T-S diagram above, the process that occurs is:

- Process 1-2: When the compressor undergoes isentropic compression

This process is the specific work of the compressor, i.e. the specific heat required to drive the compressor to the optimal position. [6]

$W_k = \dot{m}_{air}\ (h_2 - h_1)$ (1)

- Process 2-3: Combustion process in combustion chamber with constant pressure (isobar)
  This process is the process of heat entry, which can be called the amount of specific heat in the combustion chamber.
  $Q_{in} = \dot{m}_{bb}$ x LHV (2)
- Process 3-4: The isentropic process that occurs in the turbine
  This process is the working process of the turbine
  $\dot{W}_t = \dot{m}_{gas}(h_3 - h_4')$ (3)
- Process 4-1: Heat removal process at constant pressure
  This process represents the amount of specific heat in the heat dissipation process [7]
  $Q_{out} = (\dot{m}_{air} + \dot{m}_{bb})(h_4 - h_1)$ (4)

2. Methodology

In this study using quantitative methods where this method has the aim of collecting data and solving existing problems in the PLTGU loading.

2.1 Data collection technique

In order for the objectives in this study to be achieved properly, accurate data is needed as a basis for research. The author uses the following collection techniques:

- Direct Observation
- Indirect Observation
- Interview
- Literature Study

2.2 Research design

To make it easier to conduct research, the authors make a problem solving framework as shown figure 2.1.

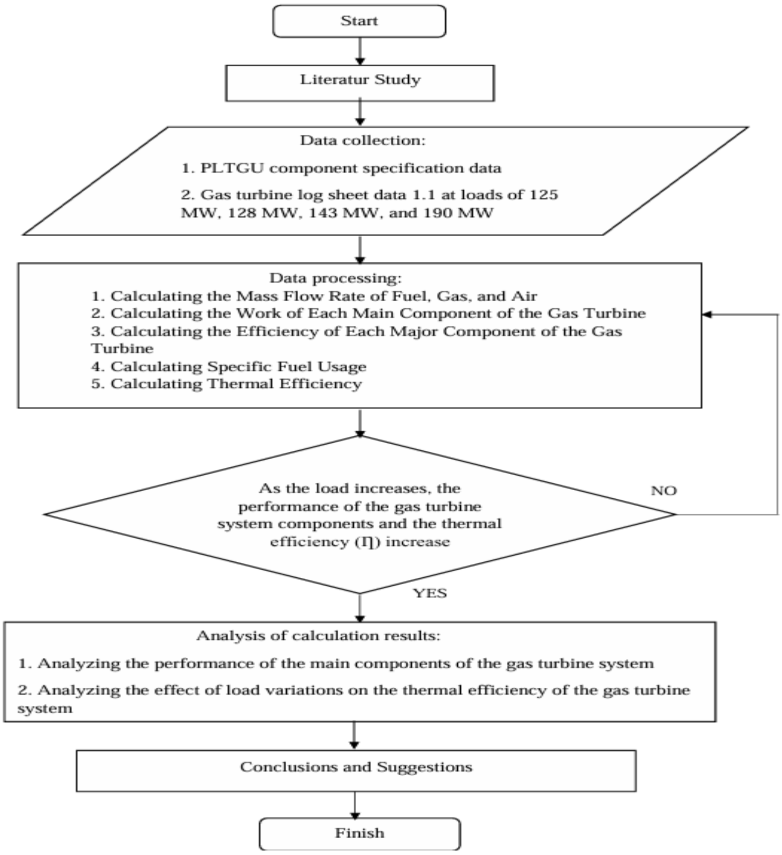


Figure 2.1 Flowchart

2.3 Calculate of gas turbine

The calculation of the mass flow rate off fuel, gas, and air cant be calculated using the equation:[8]

- Fuel Mass Flow Rate
  $$\dot{m}_{bb} = \frac{V_{bb} \text{ x } S_{bb} \text{ X } P_a}{3600} \quad (5)$$
- Air Mass Flow Rate
  $$\dot{m}_u = AFR \text{ x } \dot{m}_{bb} \quad (6)$$
- Gas Mass Flow Rate
  $$\dot{m}_g = \dot{m}_u \text{ x } \dot{m}_{bb} \quad (7)$$

The calculation of component efficiency can be calculated using the equation:[9]

- Compressor
  $$\eta_{Compressor} = \frac{h_2' - h_1}{h_2 - h_1} \text{x}100\% \quad (8)$$
- Combustion Chamber
  $$\eta_{combustion\ chamber} = \frac{(\dot{m}_u + \dot{m}_{bb})h_3 - (\dot{m}_u \text{ x } h_2)}{\dot{m}_{bb} \text{ x } LHV} \text{x}100\% \quad (9)$$
- Gas Turbine
  $$\eta_{Turbin} = \frac{h_3 - h_4}{h_3 - h_4'} \text{x}100\% \quad (10)$$

The calculation of specific fuel consumption can be calculated using the equation:

- $$SFC = \frac{\dot{m}_{bb}}{n_e} \quad (11)$$

Thermal efficiency can be defined as the ratio between the power obtained and the total fuel energy required in a period of time. Calculation of thermal efficiency is done using the equation:[10]

- $$\eta_{th} = \frac{W_{turbin} - W_{kompressor}}{Q_{in}} \text{x}100\% \quad (12)$$

3. Results and Discussion

The secondary data collected is the operational logsheet data of PT PLN Indonesia Power UP Cilegon. This data was obtained from the operator data recap in the Cilegon PLTGU CCR room.

Table 3.1 Gas Turbine Data

Gas Turbine Generator Unit 1.1							
No	Parameter	Symbol	Unit	Load			
				125 MW	128 MW	143 MW	190 MW
1.	Compressor inlet air temperature	T1	°C K	27.80 300.95	27.40 300.55	30.60 303.75	29.90 303.05
2.	Compressor outlet air temperature	T2	°C K	387 660.15	388 661.15	398 676.15	424 697.15
3.	Turbine out temperature	T4	°C K	562.00 835.15	569 842.15	598.00 871.15	593.00 866.16
4.	Compressor inlet air pressure	P1	bar	1.0132	1.0132	1.0132	1.0132
5.	Compressor outlet air pressure	P2	bar	10.45	10.53	11.25	14.17
6.	Fuel chamber out pressure	P3	bar	14.10	14.21	13.70	15.10
7.	Turbine exhaust pressure	P4	bar	194	198	209	257

Gas Turbine Generator Unit 1.1							
No	Parameter	Symbol	Unit	Load			
				125 MW	128 MW	143 MW	190 MW
8.	Fuel volume flow rate	V_{bb}	m³/s	40.401	40.988	44.605	54.716
9.	Density of air	P_a	kg/m³	1.2	1.2	1.2	1.2
10.	Spesific gravity fuel mass	S_{bb}		0.57	0.57	0.60	0.72
11.	Fuel calorific value	LHV	kJ/kg	49427.663	49486.686	49573.045	49632.020
12.	Effective power	N_e	kW	125.000	128.000	143.000	190.000

3.1. T-S Diagram

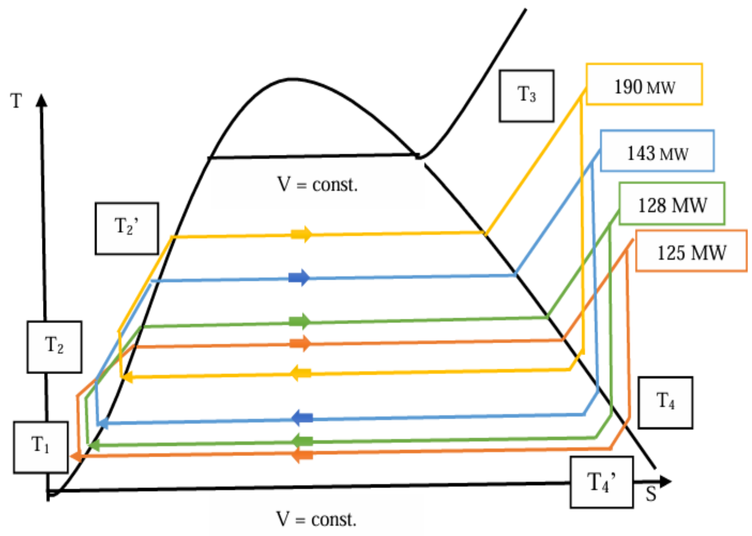


Figure 3.1 Ideal - Actual T-s Diagrams of 125 MW, 128 MW, 143 MW, and 190 MW Load

Table 3.2 T-s Diagram Results Ideal - Actual Load 125 MW, 128 MW, 143 MW, and 190 MW

Load	Unit	T_1	T_2	T_2’	T_3	T_4	T_4’
125 MW	°C	27.80	387	313.032	1214.522	562	490.635
128 MW	°C	27.40	388	313.531	1228.484	569	496.119
143 MW	°C	30.60	398	331.095	1300.236	598	517.779
190 MW	°C	29.90	424	370.791	1362.585	593	496.655

From the results obtained, the rise and fall of compressor inlet temperature (T_1) in gas turbines is usually caused by external factors such as ambient temperature, humidity, and turbine operational load, as well as internal factors such as inlet air conditioning efficiency, compressor condition, and control system. These fluctuations can affect the efficiency and overall performance of the gas turbine. For the value of the compressor exit temperature (T_2), the higher the load, the higher the results obtained. Similar to the value of T_2, at the ideal temperature of the compressor exit (T_2’) and the turbine entry temperature (T_3) the higher the load, the higher the resulting temperature. As for the turbine exit temperature (T_4) and the ideal turbine exit temperature (T_4'), there was an increase at a load of 125 MW, 128 MW, and 143 MW, then at a load of 190 MW there was a decrease in temperature, The increase and decrease in gas turbine exit temperature and ideal gas turbine exit temperature are influenced by various factors, including operational load, air-fuel ratio, fuel quality, environmental conditions, physical condition of the turbine, and the efficiency of the control and cooling system. These temperature fluctuations can affect the overall efficiency of the turbine and the life of its components.

3.2. P-V Diagram

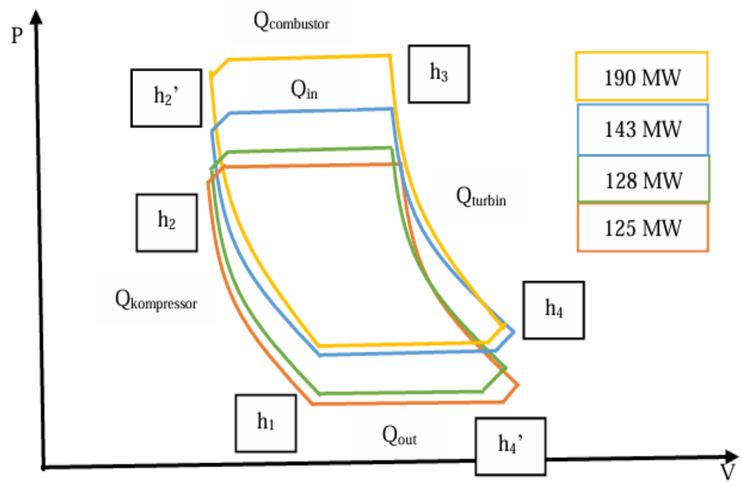


Figure 3.2 P-V Diagrams of Ideal - Actual Load 125 MW, 128 MW, 143 MW, and 190 MW

Table 3.3 P-V Diagram Results Ideal - Actual Load 125 MW, 128 MW, 143 MW, and 190 MW

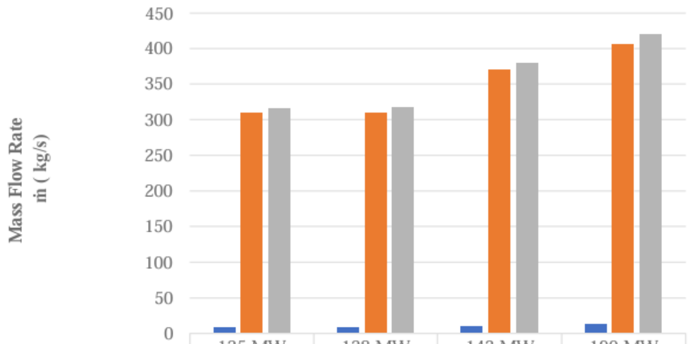
Data	Symbol	Unit	Load			
			125 MW	128 MW	143 MW	190 MW
Enthalpy of air entering the compressor	h_1	kJ/kg	301.145	300.743	303.962	303.258
Compressor out air enthalpy	h_2	kJ/kg	670.649	671.714	687.708	710.206
Enthalpy of combustion gas entering turbine	h_3	kJ/kg	1621.065	1637.952	1725.117	1801.243
Enthalpy of turbine out air	h_4	kJ/kg	860.727	868.464	900.696	895.135
Ideal enthalpy of air entering the compressor	h_2'	kJ/kg	592.518	593.041	598.237	596.805
Ideal enthalpy of turbine out air	h_4'	kJ/kg	782.317	788.311	830.526	865.855

From the results obtained above, the enthalpy value of the compressor inlet air (h_1) occurs up and down the results obtained. The ups and downs of the enthalpy of the air entering the compressor on the gas turbine are mainly caused by fluctuations in ambient air temperature and humidity, atmospheric pressure, inlet air cooling conditions, air flow velocity, as well as the influence of support systems such as anti-icing systems and filtration systems. In addition, changes in gas turbine operating load and compressor efficiency also play an important role in determining the enthalpy of intake air. These fluctuations directly affect compressor performance and the overall efficiency of the gas turbine. As for the enthalpy out of the compressor (h_2), the ideal enthalpy out of the compressor ($h_{2'}$), and the enthalpy into the turbine (h_3) increases as the loading increases. As for the turbine exit enthalpy value (h_4), it increased at loads of 125 MW, 128 MW, and 143 MW and decreased at a load of 190 MW. The increase and decrease in gas turbine exit enthalpy is caused by a variety of factors, including changes in operational load, air-fuel ratio, inlet gas pressure and temperature, turbine expansion efficiency, environmental conditions, fuel quality, and the influence of the turbine cooling and control system. The overall efficiency of the gas turbine system, as well as the physical condition of components such as turbine blades, also play an important role in determining how effectively heat energy is extracted from the gas, which affects the turbine's exit enthalpy. In contrast, the ideal turbine exit enthalpy (h_4') value rises as the loading increases.

3.3. Calculation Analysis

From the calculation of gas turbine performance to variations in loading, it can be analyzed how much influence the load variation has on the performance and therma efficiency of the gas turbine system, namely:

1. Effect of Load Variation on Mass Flow Rate of Fuel, Air, and Gas

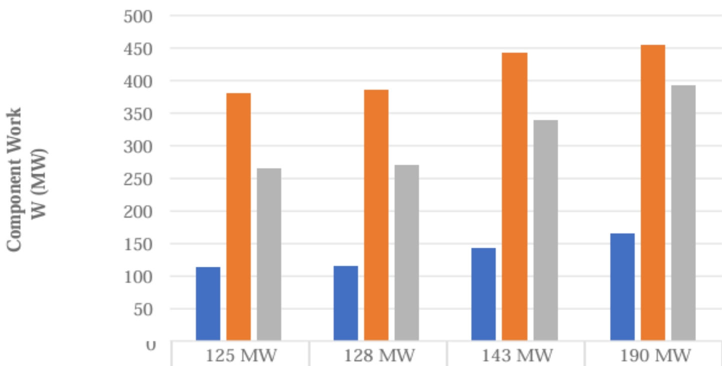


	125 MW	128 MW	143 MW	190 MW
Fuel Mass Flow Rate	7.676	7.787	8.921	13.184
Air Mass Flow Rate	308.122	309.393	370.622	405.566
Gas Mass Flow Rate	315.798	317.18	379.543	418.75

Figure 3.3 Graph of The Effect of Load Variation on Air and Gas Flow Rates

The graph above shows that in Gas Turbine Generator unit 1.1, the value of air and gas mass flow rates increases with increasing loading. The fuel mass flow rate value at 125 MW load reached 7.676 kg/s, then at 128 MW load reached 7.787 kg/s 143 MW reached 8.921 kg/s, and at 190 MW load reached 13.184 kg/s, The air mass flow rate value at 125 MW load reached 308.122 kg/s, then at 128 MW load reached 309.393 MW, then at 143 MW load reached 370.622 kg/s, and at 190 MW load reached the highest value of 405.566 kg/s, The value of the gas mass flow rate at 125 MW load reached 315.798 kg/s, then at 128 MW load reached 317.180 MW, then at 143 MW load reached 379.543 kg/s, and at 190 MW load reached 418.750 kg/s. The value of the air mass flow rate is influenced by the value of the air mass flow rate is influenced by the fuel air ratio (A / F) and the fuel mass flow rate, where the greater the value of the fuel mass flow rate, the greater the air mass flow rate.

2. Effect of Load Variation on The Working of Gas Turbine Components



	125 MW	128 MW	143 MW	190 MW
Compressor Work	113.852	114.775	142.032	165.044
Combustion Chamber Work	379.406	385.352	442.241	454.348
Turbin Work	264.874	269.489	339.535	391.693

Figure 3.4 Graph of the effect of load variation on the work of gas turbine components

When viewed from the three graphs above, it can be seen that in Gas Turbine Generator Unit 1.1, the value of compressor work, combustion chamber work (heat intake), and gas turbine work increases along with the increase in loading. The amount of compressor work is also influenced by the ambient temperature value, where the lower the compressor inlet temperature, the lighter the compressor work that is carried out. The amount of power generated increases with the increase in gas turbine inlet temperature, which means that the greater the gas turbine inlet temperature, the greater the gas turbine work. From the analysis of the graph above, there are several factors that affect the thermal efficiency of PLTG unit 1.1, such as network, incoming heat value, and environmental air temperature.

3. Effect of Load Variation on Gas Turbine Component Efficiency

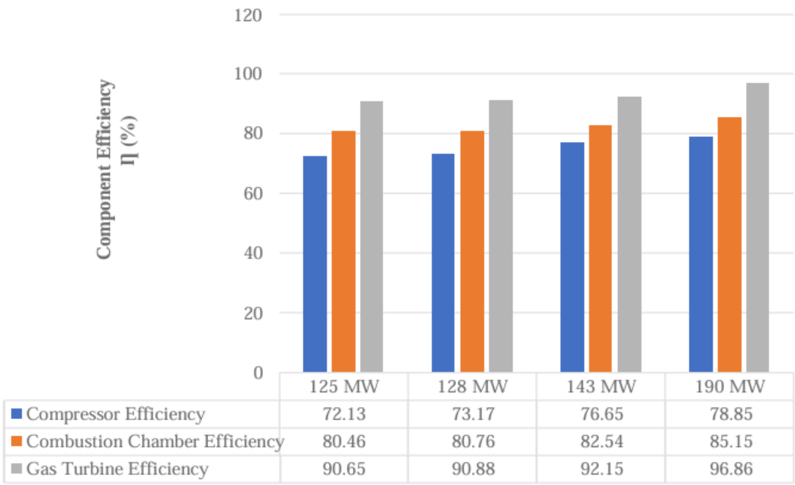


Figure 3.5 Graph of The Effect of Load Variation on The Efficiency of Gas Turbine Components

The energy efficiency test results of each component of the PLTG recorded during the performance test showed that the compressor, gas turbine, and combustion chamber increased energy efficiency as the loading increased. An increase in loading results in an increase in the efficiency of the compressor components. This increase is due to an increase in airflow rate in various loading variations, but a decrease in airflow rate can lead to a decrease in compressor efficiency.

For the combustion chamber, the air mass flow rate increases as the loading increases, the smaller the air flow rate used in the combustion process, the lower the efficiency. The efficiency of the combustion chamber also depends on how much enthalpy is produced when air enters the gas turbine.

For the gas turbine component, the efficiency is almost the same at around 90%, and there is an increase in the efficiency graph as the loading increases. This increase is due to the increase in the enthalpy value of the combustion gas entering the turbine, which also increases with different loadings. Thus, to increase the efficiency of gas turbine components, it can be done by increasing the turbine gas inlet enthalpy value (T_3) and the turbine exit enthalpy value (T_4).

4. Effect of Load Variation on Specific Fuel Consumption

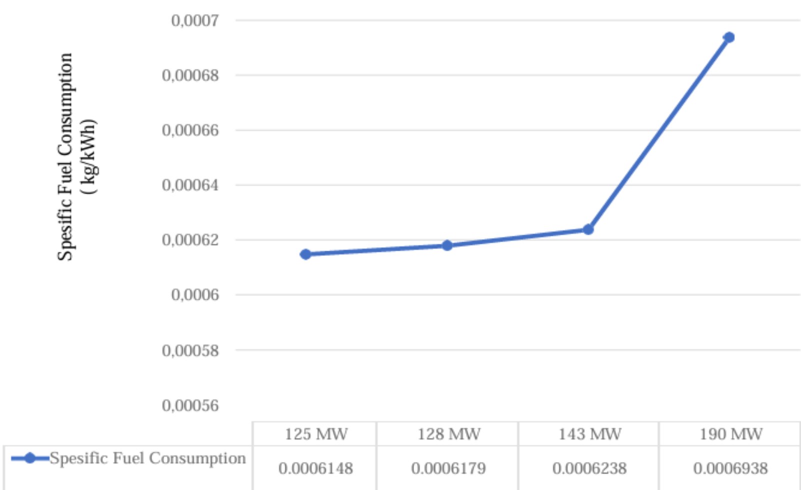


Figure 3.6 Graph of The Effect of Load Variation on Specific Fuel Consumption

The gas turbine load is positively correlated with the specific fuel consumption (SFC) in the combustion process. As a result, the fuel combustion process becomes more complete, which results in increased heat energy (Q_{in}) in the combustion chamber. As a result, the gas turbine cycle becomes more efficient. Another factor that affects the increase in fuel consumption is the fuel mass flow rate; the higher the fuel mass flow rate and the loading, the more specific fuel consumption is used in the gas turbine.

5. Effect of Load Variation on Thermal Efficiency

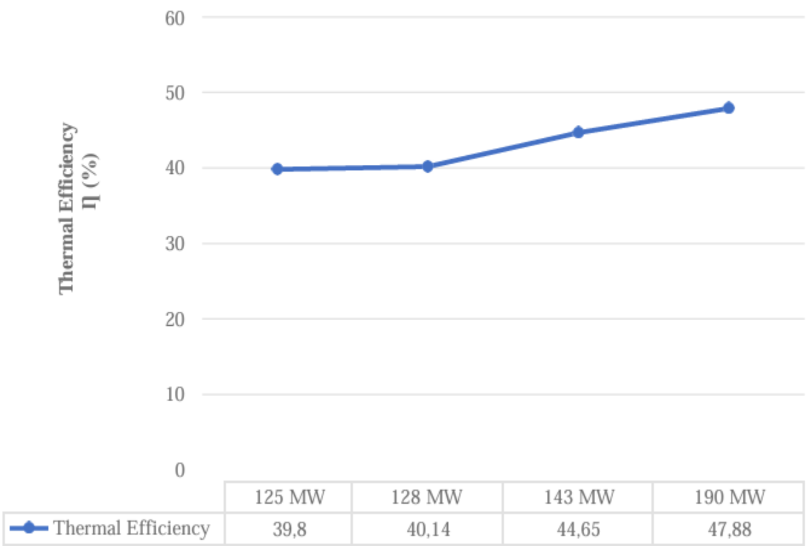


Figure 3.7 Graph of The Effect of Load Variation on Thermal Efficiency

The graph above shows that the greater the load on the gas turbine, the higher the thermal efficiency. This can happen because the load on the turbine increases the combustion process in heat and combustion chamber resulting from combustion, as a result more heat is absorbed for turbine work to increase the thermal efficiency of the gas turbine. In addition, the value of compressor work and the value of gas turbine work also greatly affects the resulting thermal efficiency. Most power plants are designed to achieve maximum thermal efficiency at or near their full load capacity. At this point, all components, such as boilers, turbines, and generators, are operating optimally. load has a 50% influence contribution.

4. Conclusions

The results of the research and calculation of the analysis of the effect of load variations on the performance of the gas turbine generator 1.1 at PT PLN (Persero) Cilegon Power UP show that the value of the gas turbine system performance parameters changes along with the generator load, which shows that with greater load, gas turbine system performance improvement. At a load of 190 MW, the performance of the gas turbine system is improved, with a fuel mass flow rate of 13.184 kg/s, an air mass flow rate of 405.566 kg/s, a gas mass flow rate of 418.750 kg/s, a compressor work of 165.044 MW with an efficiency of 78.85%, a combustion chamber work of 454.348 MW with an efficiency of 85 15%, and a gas turbine work of 391 MW with an efficiency of 96.86%, and the lowest specific fuel consumption of 0.0006938 kg/kWh. The 190 MW load has the highest thermal efficiency of 47.88%, and 125 MW has the lowest thermal efficiency of 39.80%.

5. Acknowledgements

The author would like to thank the parties who have supported the preparation of this research, thanks are given to Dr.Ir. Edy Susanto S.T, M.T, IPM as the supervisor, Faculty of Business Technology and Energy, PLN Institute of Technology S1 Mechanical Engineering study program that has helped smooth the preparation of this research, PT PLN Indonesia Power UP Cilegon, staff and employees who have given the opportunity to collect data and study in the field of generation industry, parents, siblings and families who always provide support during the process of preparing this research.
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