ANALYSIS OF THE OPERATIONAL EFFICIENCY OF THE GTG 2.2 SYSTEM AT TAMBAK LOROK GAS AND STEAM POWER PLANT

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Abstract – *With the rise of electricity demand in Indonesia, a reliable power plant is needed so that a system in the generating unit with maximum efficiency is required. In the electricity generation unit, there are some components used in the generation process. The amount of energy produced by the generating system can be influenced by several factors, one of which is the efficiency of the equipment components such as compressors, turbines, and systems in the Gas Turbine Generator (GTG) 2.2 unit.*

PT Indonesia Power Unit Pembangkitan Semarang is one of the electric power generation companies that manages 3 PLTU units and 2 PLTGU blocks with a total installed capacity of 1,313.33 MW. At PLTGU on GTG 2.2, this system operates continuously starting from the primary load, medium load to peak load. Thus, it is necessary to analyze the efficiency of the operating system in GTG 2.2 because it can affect the distribution of electrical energy.

After the calculation, it can be concluded as the calculation of results the highest and lowest efficiency values on the compressor, turbine, and GTG 2.2 system at PT. Indonesia Power UP Semarang during 7 consecutive days of operation. The highest efficiency was 92.03%, 83.41%, and 35.91%. Meanwhile, the efficiency the lowest was 90.58%, 76.62%, and 29.82% respectively. To maintain the operational efficiency of the system so it can be improved continuously, then they need to provide the balance of using fuel and the incoming air because it affects the power generated.

Keywords*: Gas Turbine Generator, Efficiency, Equipment components.*

I. INTRODUCTION

The availability of efficient electricity at affordable prices is an important factor to support the Indonesian economy. Nowadays, the availability of national electricity is having problems due to the limited supply compared to the increasing needs. In some areas there is a gas fuel crisis due to infrastructure making it difficult to distribute. In addition, community access to energy is still limited, especially in disadvantaged, remote and border areas.

With the increasing electricity demand in Indonesia, a reliable power plant is needed so that a system in the generating unit is needed with maximum efficiency. In the electricity generation unit there are several components used during the electricity generation process. The amount of energy capacity produced by the generating system can be influenced by several factors, one of which is the efficiency of the components of the system.

PT Indonesia Power Generation Unit Semarang is a subsidiary of PT PLN (PERSERO), which is one of the power plants that manages 3 PLTU units and 2 PLTGU blocks with a total installed capacity of 1,313.33 MW. At PLTGU on GTG 2.2, this system operates continuously starting from basic load, medium load to peak load. So it needs to be analyzed the efficiency of the operational system because it can affect the distribution of electrical energy.

II. GAS TURBINE GENERATOR (GTG)

Gas turbines are energy driving machines that work by burning the root material in an open flame that produces heat energy. The energy that has been generated is then flowed using a machine to hardware using a working fluid in the form of air. The process contained in the gas turbine in the form of air taking, compression, heating, and disposal conducted in sequence (Pudjanarsa & Nursuhud, 2012).

The main components contained in the GTG consist of a compressor, combustion chamber, and turbine

II.1. Compressor

The main component in this section is the *axial flow compressor,* which functions to compress the air coming from the *inlet air section* to high pressure, so that during combustion can produce high-speed hot gas that can cause a large turbine *output* power. The type of compressor used is a 17-level axial compressor with a pressure ratio of 10 bar, which consists of an incoming directional blade, a 17-level rotor and stator and an outgoing directional blade. Compressor rotor blades consist of 4 main parts, which is the *inlet casing* located at the end of the compressor, *forward casing* consisting of the first 4 levels, *aft casing* consisting of compressor blades level 5 to 10, and *discharge casing* which is the final part of the compressor consisted of 7 levels.

II.2. Combustion Chamber

The combustion chamber is a component where the combustion process occurs. The compressed air which has a high *pressure* will be mixed with gas fuel and the combustion process will be assisted with sparks from the spark plug. This process serves to add heat value to the gas.

II.3. Turbines

Gas turbine is an *energy conversion machine* that utilizes fluid energy in the form of gas. The function of a gas turbine is to drive loads like a generator. In a simple turbine consists of several parts, namely the rotor is a rotating part there is a *shaft* with *blades* mounted on the *rotor*. This *rotor* can work because of a fluid impulse or can spin due to the reaction of the fluid.

III. EFFICIENCY CALCULATION

III.1. Actual Performance and Compressor Efficiency

- Calculating actual compressor performance ($\mathrm{W_{ca}}$)

$$\mathrm{W_{ca}} = \frac{\dot{\mathrm{m}}_{\mathrm{ud}}.(\mathrm{h_2} - \mathrm{h_1})}{\eta_\mathrm{c}}$$

- Calculating compressor efficiency (η_c)

$$\eta_\mathrm{c} = \frac{\mathrm{h'_2} - \mathrm{h_1}}{\mathrm{h_2} - \mathrm{h_1}} \times 100\%$$

Where $\mathrm{h'_2}$ is the enthalpy value of $\mathrm{T'_2}$ calculated in the formula

$$\mathrm{T'_2} = \mathrm{T_1}\left(\frac{\mathrm{P_2}}{\mathrm{P_1}}\right)^{\frac{k-1}{k}}$$

III.2. Combustion Chamber

- Calculating the entry heat value ($\mathrm{Q_{in}}$)

$$\mathrm{Q_{in}} = \dot{\mathrm{m}}_{\mathrm{BB}}.\mathrm{NK_{BB}}$$

- Calculating Airflow Rate

$$\dot{\mathrm{m}}_{\mathrm{ud}} = \frac{\mathrm{Q_{in}} - (\dot{\mathrm{m}}_{\mathrm{BB}}.\mathrm{h_3})}{(\mathrm{h_3} - \mathrm{h_2})}$$

III.3. Actual Performance and Turbine Efficiency

- Calculating actual turbines performance ($\mathrm{W_{ta}}$)

$$\mathrm{W_{ta}} = (\dot{\mathrm{m}}_{\mathrm{ud}} + \dot{\mathrm{m}}_{\mathrm{bb}}).(\mathrm{h_3} - \mathrm{h_4}).\eta_\mathrm{t}$$

- Calculating turbines efficiency (η_t)

$$\eta_\mathrm{t} = \frac{\mathrm{h_3} - \mathrm{h_4}}{\mathrm{h_3} - \mathrm{h'_4}} \times 100\%$$

Where $\mathrm{h'_4}$ is enthalpy of $\mathrm{T'_4}$, the value is calculated in the following:

$$\mathrm{T'_4} = \mathrm{T_3}\left(\frac{\mathrm{P_4}}{\mathrm{P_3}}\right)^{\frac{k-1}{k}}$$

III.4. Thermal Efficiency

$$\eta_{\mathrm{th}} = \frac{\mathrm{W_{ta}} - \mathrm{W_{ca}}}{\dot{\mathrm{m}}_{\mathrm{BB}} - \mathrm{NK_{BB}}} \times 100\%$$

IV. METHODOLOGY

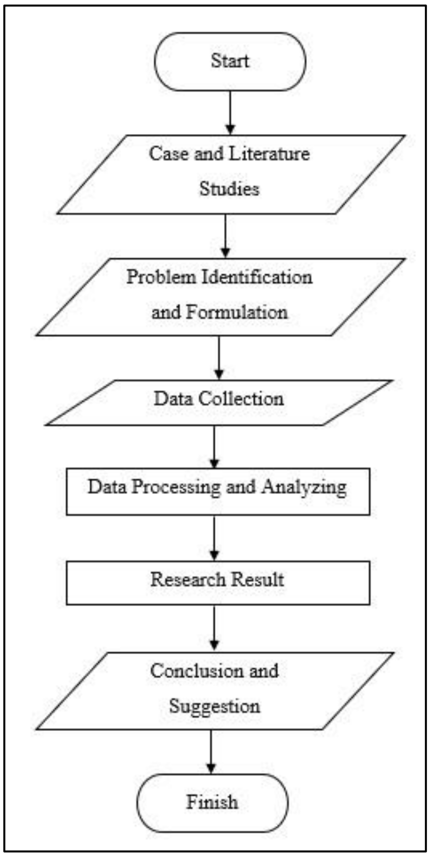


Figure 1 Research Flow Diagram

The research and thesis entitled Operational Efficiency Analysis on GTG 2.2 PT Indonesia Power Tambak Lorok was divided into 6 phases as follows:

- Case and literature studies

Case study was a method used to investigate and study an object (Bimi walgito, 2010). The case study process was conducted by studying books or journals, observing problems directly in the field, and conducting interviews with those who know the area.

Literature study was conducted in order to get the general picture discussed, covering the background of the problem to research on the analysis of the efficiency of the PLTGU which was previously presented in Chapter 2.

- Problem Identification and Formulation

Problem identification was conducted to find out the problems that occur in the field. After the problem was known, the problem formulation was conducted to be used as a reference during the research process carried out as well as the design of the concept on the target in completion. Problem identification can also get the needs of industry, society, and the government concerned.

- Data collection

The next process was the process of collecting data to support the efficiency analysis of the generating system which was conducted directly in the field by conducting observations, conducting interviews with competent parties in their fields, and collecting various data. Data collected in the form of secondary data.

The required data are P_1 (ambient air pressure), P_2 (*absolute* pressure), P_4 (outside turbine pressure), T_1 (ambient air *temperature*), T_2 (compressor outlet *temperature*), T_4 (turbine outlet *temperature*), and generator output power obtained from the operator's part using MarkV *software*. In addition, fuel data in the form of density and calorific values are also needed obtained from the EPMO division (Primary Energy and Operating Materials).

- Data processing and analyzing

After the required data had been collected, the next step was to perform data processing in the form of calculations using the formulas listed in Chapter 2. Then the results of these calculations were analyzed systematically.

- Research result

The research results obtained from the calculation results that have been analyzed and processed in the form of tables and graphs.

- Conclusion and suggestion

The last stage was the conclusion regarding the results of the research that were aligned with the objectives of the research conducted. In addition to the conclusions there are suggestions for readers regarding the research that had been done.

V. RESULT AND DISCUSSION

One example of the calculation is taken from one of the data which is on June 17, 2019 at 01.00 WIB.

- **Condition 1**

In this condition, the air entering the compressor is obtained from the environment (atmospheric air) through the *air inlet*. P1 value is the atmospheric pressure obtained from the measurement using the barometer listed in the attachment.

P_1 = 76 mmHg = 1.01325 bar

T_1 = 26.46 °C = 299.61 K

The enthalpy air value is calculated using the interpolation formula and thermodynamic table from the book entitled "Thermodynamics An Engineering Approach 5th edition" written by Yunus A. Chengel and Michael A. Boles on Table A-17.

$$h_1 = \frac{(T_1 - T_{below})(h_{upper} - h_{below})}{(T_{upper} - T_{below})} + h_{below}$$

$$= \frac{(299.61 - 298)(300.19 - 298.18)}{(300 - 298)} + 298.18$$

$= 299.79\ ^{kJ}/_{kg}$

- **Condition 2**

In this condition the air will be compressed to the combustion chamber with the following *temperature* and pressure:

P_2 = 9.98 bar

T_2 = 351.97 °C = 625.12 K

To find the enthalpy value of the air, use the same method as before.

$$h_2 = \frac{(T_2 - T_{below})(h_{upper} - h_{below})}{(T_{upper} - T_{below})} + h_{below}$$

$$= \frac{(625.12 - 620)(638.63 - 628.07)}{(630 - 620)} + 628.07$$

$= 633.47\ ^{kJ}/_{kg}$

Because the condition obtained is an ideal condition, this condition takes isentropic compression process which gets the Pr1 value as follows

$$Pr_1 = \frac{(T_1 - T_{below})(Pr_{upper} - Pr_{below})}{(T_{upper} - T_{below})} + Pr_{below}$$

$$= \frac{(299.61 - 298)(1.3860 - 1.3543)}{(300 - 298)} + 1.3543$$

$= 1.38\ ^{kJ}/_{kg}$

$$Pr'_2 = Pr_1 \left(\frac{P_2}{P_1}\right)$$

$$= 1.3798 \left(\frac{9.98}{1.01}\right)$$

$= 13.59\ ^{kJ}/_{kg}$

From Pr_{2s} value obtained is used to find the enthalpy of air using the same interpolation and table as before.

$$h'_2 = \frac{(Pr_{2s} - Pr_{below})(h_{upper} - h_{below})}{(Pr_{upper} - Pr_{below})} + h_{below}$$

$$= \frac{(13.59 - 13.50)(586.04 - 575.59)}{(14.38 - 13.50)} + 575.59$$

$= 576.66\ ^{kJ}/_{kg}$

- **Condition 3**

This condition occurs the combustion process in the *combustion chamber*, fuel in the form of gas will be mixed with air that was previously compressed on the compressor and the lighter used for the combustion process to take place. Fluid from the combustion will exit into the turbine to move the blades on the turbine which will convert the combustion fluid energy into motion energy.

T_4 = 560.54 °C = 833.69 K

$$Pr_4 = \frac{(T_4 - T_{below})(Pr_{upper} - Pr_{below})}{(T_{upper} - T_{below})} + Pr_{below}$$

$$= \frac{(833.6\ 820)(57.60 - 52.59)}{(840 - 820)} + 52.59$$

$=56.02\ ^{kJ}/_{kg}$

Assuming $P_3 = P_2$

$$Pr_3 = Pr_4 \left(\frac{P_3}{P_4}\right)$$

$$= 56.02 \left(\frac{9.98}{1.01}\right)$$

$= 551.67\ {}^{kJ}/_{kg}$

$$h_3 = \frac{(Pr_3 - Pr_{below})(h_{upper} - h_{below})}{(Pr_{upper} - Pr_{below})} + h_{below}$$

$$= \frac{(551.67 - 537.10)(1611.79 - 1587.63)}{(568.80 - 537.10)} + 1587.63$$

$= 1598.80\ {}^{kJ}/_{kg}$

The value of T_3 cannot be known by the system because the temperature is too high, it can be calculated using interpolation and the ideal gas table using the results of h_3 that have been obtained previously.

$$T_3 = \frac{(h_3 - h_{below})(T_{upper} - T_{below})}{(h_{upper} - h_{below})} + T_{upper}$$

$$= \frac{(1598.80 - 1587.63)(1480 - 1460)}{(1480 - 1460)} + 1460$$

$= 1469.25$ K

- **Condition 4**

Condition 4 occurs the process of expansion of the exhaust gas from the combustion results in the turbine. This exhaust gas *temperature* becomes higher than the ideal gas, it is due to the friction process between the combustion gases and the blades in the turbine. To find the enthalpy value, an interpolation formula and an ideal gas table with T_4 values obtained through operator data are used.

$$h_4 = \frac{(T_4 - T_{below})(h_{upper} - h_{below})}{(T_{upper} - T_{below})} + h_{below}$$

$$= \frac{(833.69 - 820)(866.08 - 848.98)}{(840 - 820)} + 843.98$$

$= 859.11\ {}^{kJ}/_{kg}$

Because the ideal conditions are obtained in this condition, then an isentropic process occurs which can be calculated with a constant k of 1.4. Assuming the value of $P_4=P_1$ and $P_2=P_3$

$$T'_4 = T_3 \left(\frac{P_4}{P_3}\right)^{\frac{k-1}{k}}$$

$$= 1469.25 \left(\frac{1.01}{9.98}\right)^{\frac{1.4-1}{1.4}}$$

$= 764.30$ K

From the result of T_{4s} obtained, then it can calculate the isentropic enthalpy value.

$$h'_4 = \frac{(T'_4 - T_{below})(h_{upper} - h_{below})}{(T_{upper} - T_{below})} + h_{below}$$

$$= \frac{(764.30 - 760)(800.03 - 778.18)}{(780 - 760)} + 778.18$$

$= 782.88\ {}^{kJ}/_{kg}$

- **Entry Heat**

$Q_{in} = \dot{m}_{BB} \times NK_{BB}$

$= 6.34 \times 54258.23$

$= 343997.24\ {}^{kJ}/_{s}$

- **Airflow Rate**

From the calculation of the incoming heat value, it can be calculated the rate of incoming air flow with the values h_3 and h_2 that have been obtained from previous calculations.

$$\dot{m}_{ud} = \frac{Q_{in} - (\dot{m}_{BB} . h_3)}{(h_3 - h_2)}$$

$$= \frac{343997.17 - (6.34 - 1598.80)}{(1598.80 - 633.47)}$$

$= 334.72\ {}^{kg}/_{s}$

- **Compressor Performance**

a. Compressor efficiency

The compressor efficiency value is

$$\eta_c = \frac{h'_2 - h_1}{h_2 - h_1} \times 100\%$$

$$= \frac{576.66 - 299.79}{633.47 - 299.79} \times 100\%$$

$= 82.97$ %

b. Compressor actual performance

The actual performance value of the compressor is

$$W_{ca} = \frac{\dot{m}_{ud}\,(h_2 - h_1)}{\eta_c}$$

$$= \frac{345.85\,(633.47 - 299.79)}{0.82}$$

$= 139083.80\ {}^{kJ}/_{s}$

- **Turbines Performance**

a. Turbines efficiency

$$\eta_t = \frac{h_3 - h_4}{h_3 - h'_4} \times 100\%$$

$$= \frac{1598.80 - 859.11}{1598.80 - 782.88} \times 100\%$$

= 91 %

b. Turbine actual performance

$$W_{ta} = (\dot{m}_{ud} + \dot{m}_{BB}).(h_3 - h_4)$$

= (345.85 + 6.34) (1598.80 – 859.11)

= 260515.62 $^{kJ}/_{s}$

- **System Efficiency**

The system efficiency value on GTG 2.2 for data on June 17, 2019 at 01.00

$$\eta_{th} = \frac{W_{ta} - W_{ca}}{\dot{m}_{BB} \times NK_{BB}} \times 100\%$$

$$= \frac{260515.62 - 139083.80}{6.34 \times 54258.23} \times 100\%$$

= 35.30 %

The following graph is the results of the calculation of the efficiency values of compressors, turbines, and systems on GTG 2.2 starting from June 17, 2019 to June 23, 2019

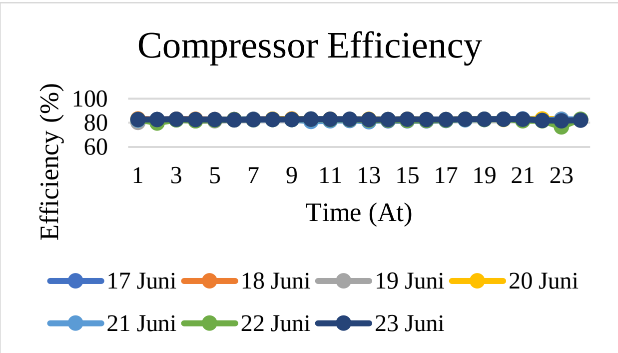


Figure 2 Graph of Compressor Efficiency Calculation Results

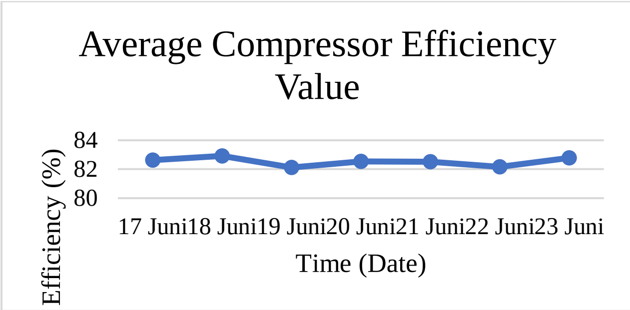


Figure 3 Graph of Average Value of Compressor Efficiency Calculation Results

From the calculation result conducted and presented in Figure 2 the highest result of compressor efficiency is 83.41% at 22.00 on June 20th 2019 and the lowest efficiency is at 22.00 on June 23th 2019 which is 76.62%. Efficiency of compressor is affected by the magnitude of T_1, T_2, and P_2 values. After calculation in each our is conducted, the average value in each day is taken. Based on Figure 3 which is average of compressor efficiency in each day, the highest efficiency is on June 18th 2019 which is 82.96% and the lowest efficiency is on June 19th 2019 which is 82.12%. Seen from the result, the average of efficiency value is categorized as good.

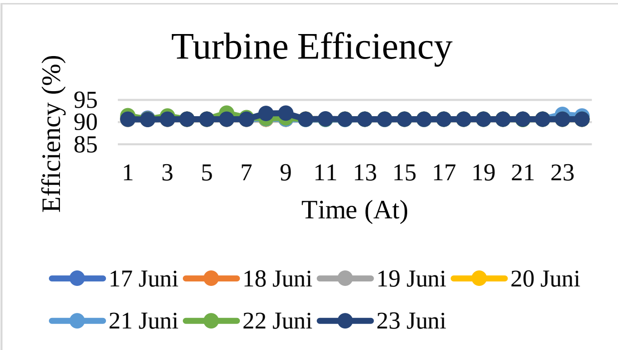


Figure 4 Graph of Turbine Efficiency Calculation Result

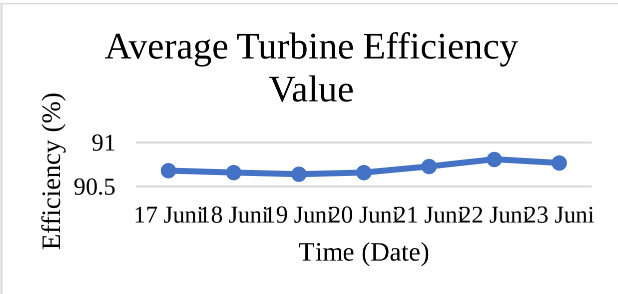


Figure 5 Graph of Average Value of Turbine Efficiency Calculation Result

Based on the calculation result presented in Figure 4, it can be seen that the highest turbine efficiency is 92.03% at 06.00 on June 22th, 2019 and the lowest efficiency is at 23.00 on June 22th, 2019 which is 90.57%. Based on Figure 5, the average efficiency of turbine each day obtained the highest efficiency on June 22, 2019, amounting to 90.80% and the lowest efficiency on June 19, 2019, 90.64%. The value of the efficiency of the turbine is influenced by the magnitude of the value of T_3, T_4, and P_3.

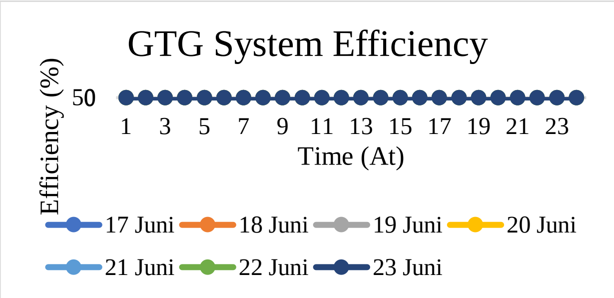
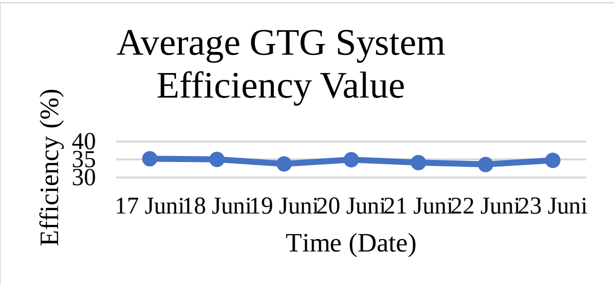


Figure 6 Graph of System Efficiency Calculation Result in GTG 2.2



Graph 7 Graph of Average Value of Efficiency Calculation Result In GTG 2.2 System

From the calculation result presented in Figure 6, it can be seen that the highest efficiency results from the efficiency of the GTG 2.2 system is 35.91% at 03.00 on June 23th, 2019 and the lowest efficiency is at 23.00 on June 22th, 2019 which is 28.92%. Based on Figure 7, the average efficiency each day obtained the highest efficiency on June 17, 2019, amounting to 34.30% and the lowest efficiency on June 22, 2019, 33.65%.

The efficiency value in GTG system is affected by exhaust gas *temperature* which is in T_4 in condition 4. The efficiency value will be maximum if the *temperature* and the *pressure* in condition 4 has high value, but the value has maximum which is predetermined in tool specification which is with *temperature* for 550.8 °C and *pressure* amounting 1.045 bar. Based on book entitled "*Gas Turbine Engineering Handbook 2nd*" by Meherwan P. Boyce, it explains the ideal vale of efficiency in GTG which has capacity ranged 3 MW to 480 MW which is around 30%-46%. From the calculation result, it can be known that the efficiency value in GTG 2.2 can be categorized as normal passes minimum limit of ideal value range of efficiency value.

Analysis

Based on the calculation result obtained the highest efficiency result from compressor, turbine and system respectively 92.03%, 83.41%, and 35.91%. while the lowest efficiency respectively are 90.58%, 76.62% and 29.82%.

Fuel flow rate and heat value affects the efficiency value in system because when the combustion process, the fuel used and the incoming air must be balanced. The balance between fuel and incoming air will affect the power generated.

The amount of efficiency value in system is affected by *temperature* value and exhaust gas which is in condition 4. The higher the *temperature* and the *pressure*, then the efficiency resulted will be higher, but the high of *temperature* and *pressure* value in exhaust gas has maximum value which is 550.8 ℃ and 1.045 bar. That maximum limit is obtained based on tool specification. In addition, system efficiency value can increase with increasing power generated and the amount of energy in the fuel used.

Based on book entitled "*Gas Turbine Engineering Handbook 2nd*" by Meherwan P. Boyce, the ideal of system efficiency value in GTG with increasing power generated and the amount of energy in the fuel used.

Exhaust gas in turbine has a very high energy which can be utilized for heating process that can be conducted in *Steam*

Turbine Generator (STG) unit. For the generation unit at PT Indonesia Power Semarang already utilizes the flue gas.

To increase the efficiency value of GTG 2.2 can be installed an *intercooler* in compressor so that the incoming air has lower *temperature* so that it can result *output* power which is more maximum. The addition of temperature in *inlet guide vane* can help to optimize the combustion process which is useful to manage the incoming air flow rate. In addition, routine maintenance on regular basis is needed to maintain the performance of each component.

VI. CONCLUSION

After research on system efficiency in GTG 2.2 is conducted, the conclusion that can be drawn is as follows:

1. Highest efficiency value in compressor, turbine, and system in GTG 2.2 respectively are 92.03%, 83.41%, and 35.91%. while the lowest efficiency respectively is 90.58%, 76.62%, dan 29.82%.
2. Load fluctuation, *temperature*, and *pressure* affects efficiency value in GTG system.
3. The higher the temperature and pressure values, the result of the efficiency will increase, but the value has maximum limit.
4. The balance of usage between fuel and incoming air will affect the power resulted.

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VIII. BIOGRAPHY

Marinta Hardianti was born in Pontianak on March 18th, 1998. The formal education that has been taken is State Elementary School 24 North Pontianak (2004-2010), State JHS 7 Pontianak (2010-2013), State SHS 3 Pontianak (2013-2016). Then in 2016 the writer was accepted as a student of the Muhammadiyah University Yogyakarta (UMY) at the Faculty of Engineering, Electrical Engineering Study Program.

In 2019, the writer conducted research entitled **“Analysis of the Operational Efficiency of the GTG 2.2 System at Tambak Lorok Gas and Steam Power Plant”**. The research that has been conducted by the writer as requirement to obtain bachelor degree.