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PYTHON-BASED ENERGY AND EXERGY ANALYSIS FOR EFFICIENT EVALUATION OF STEAM TURBINE PERFORMANCErticle Title Here

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ABSTRACT
Gas and Steam Power Plant (PLTGU) is a thermal power plant that has been in use since 1901. Over time, the energy and exergy analysis of PLTGU must be a fast analysis and takes very little time. This study aims to analyze the energy and exergy of one of the PLTGU components, namely the steam turbine using the python programming language, so that the analysis can be carried out quickly. As a theoretical basis to be able to carry out energy and exergy analysis of PLTGU steam turbines. The objects analyzed are: system input energy, isentropic efficiency, turbine work, energy loss rate, turbine energy efficiency, system exergy, fuel and product exergy, exergy destruction rate, and exergy efficiency. In carrying out the analysis, the theory used is the laws of thermodynamics 1 and 2. The results of the analysis are carried out according to the adopted theory, the isentropic efficiency of the steam turbine is in the range of70% to 97%, the exergy of the system will always be greater than the energy of the system, the exergy of fuel is greater than product exergy, and the exergy efficiency of steam turbines is above 93%. It can be concluded from this research, that the steam turbine can still be operated for the next few years.

Keywords: *Energy, Exergy, Gas and Steam Power Plant, Steam Turbines, Python*

1. INTRODUCTION

PLTGU (Gas and Steam Power Plant) is a combination of two thermal power plants (combine cycle), namely PLTG and (PLTU) [1]. Therefore PLTGU has a higher efficiency when compared to other thermal power plants [2]. PLTGU components include compressors, combustion chambers, gas turbines, pumps, Heat Recovery Steam Generators (HRSG), steam turbines, condensers and generators [3]. PLTU is a power plant that works based on the rankine cycle. Rankine cycle is a cycle in which phase changes occur, namely during condensation and evaporation. There are three kinds of rankine cycles, namely the ideal rankine cycle, the rankine cycle with reheating, and the regenerative rankine cycle [4]. An ideal rankine cycle is a cycle that occurs under ideal or theoretical conditions [2]. The rankine cycle with reheating is the rankine cycle in which the turbine work alternates, first with a high pressure turbine, then with a medium pressure turbine, finally with a low pressure turbine[4]. The regenerative rankine cycle is a cycle that uses a water heater before entering the boiler or HRSG [5]. The components of the PLTU consist of a water feed pump , HRSG, steam turbine and condenser [6]. Each PLTGU unit has more than 1 department, one of the departments in PLTGU is the Central Control Room (CCR). CCR is a place where control and data input are carried out. Inside the CCR there is data from the start of operation (commissioning) to the current data, which can hamper the data analysis process. Therefore this research was conducted to speed up the data analysis process and find out whether the steam turbine is still feasible to operate for the next few years with the maintenance that has been implemented. Some data that can be analyzed from PLTGU are energy, isentropic efficiency, work, energy loss rate, total efficiency of the steam turbine, exergy, exergy destruction rate, exergy efficiency, and others.

To calculate complex and widely used data sets Python programming language to ease the course of research.

1.1. Power plant

PLTU is a thermal power plant that uses steam as a driving force to produce electrical energy. In PLTU, three energy conversion processes occur, namely chemical energy from fuel which is converted into heat energy in the form of water vapor, heat energy is converted into mechanical energy in the form of rotation of the turbine shaft, and mechanical energy is converted into electrical energy in a steam turbine generator [5]. The advantages of the PLTU are the high efficiency it produces, the power it can produce is relatively large, it is flexible in the use of fuel (for example, in PLTGU PT X, the PLTU uses exhaust gas from a gas turbine), it is relatively more durable, inspections do not need to be as intensive as other generators. , and lower maintenance costs [7].

1.2. Steam turbine

The steam turbine is one of the PLTU components that works as an energy conversion machine from the potential energy of steam into kinetic energy, then converted back into mechanical energy [8]. The PLTU steam turbine has 3 levels of steam pressure, namely High Pressure (HP), Intermediate Pressure (IP), and Low Pressure (LP) turbines [5]. The advantages of a steam turbine compared to a steam engine are that its components are simpler, more stable, there are no losses due to friction in its rotation, with the same size, a steam turbine will produce more power [9].

2. FUNDAMENTALS OF THERMODYNAMICS

There are 4 stages in the Rankine cycle, namely isentropic expansion in the turbine, heat release from the working fluid to the condenser, isentropic compression by the water feed pump , and heat absorption to the working fluid in the HRSG.

2.1 Enthalpy

Enthalpy is the amount of internal energy contained in 1 kg of substance. To find out the enthalpy value, linear interpolation techniques [10]and fractions [4]can be used. The enthalpy values sought are specific enthalpy (h) and isentropic enthalpy (h_s) . Specific enthalpy is the enthalpy under conditions where temperature and pressure are not directly indicated in the property table.

$$h_x = h_1 + \frac{P_x - P_1}{P_2 - P_1}(h_2 - h_1) \quad (1)$$

$$h_x = h_1 + \frac{T_x - T_1}{T_2 - T_1}(h_2 - h_1) \quad (2)$$

Isentropic enthalpy is enthalpy under conditions where the entropy of a substance is constant [4]. To find the enthalpy value, the fraction technique is used.

$$x_s = \frac{s_s - s_f}{s_{fg}} \quad (3)$$

$$h_s = h_f + x_s h_{fg} \quad (4)$$

2.2 Entropy

Entropy is a value that can describe the disorder in a system, which arises because of the statement of the 2nd law of thermodynamics, where all heat cannot be fully utilized as work, and this heat can only move from high to low temperatures.

$$s_x = s_1 + \frac{P_x - P_1}{P_2 - P_1}(s_2 - s_1) \quad (5)$$

$$s_x = s_1 + \frac{T_x - T_1}{T_2 - T_1}(s_2 - s_1) \quad (6)$$

2.3 Energy Analysis

The energy from the steam turbine is analyzed in 5 parts, namely total energy, isentropic efficiency, total work, energy loss rate, and total energy efficiency of the steam turbine [11].

a. Total energy

$$E = \dot{m}(h_i - h_o) \quad (7)$$

b. Isentropic efficiency

$$\eta = \frac{h_i - h_o}{h_i - h_{s.o}} * 100\% \quad (8)$$

c. Total work

$$W = E * \eta \quad (9)$$

d. Energy loss rate

$$Q_{loss} = E - W \quad (10)$$

e. Energy efficiency

$$\eta_{energi} = 1 - \frac{Q_{losstotal}}{E_{total}} \quad (11)$$

2.4 Exergy Analysis

Exergy is divided into four, namely physical exergy, kinetic exergy, potential exergy, and chemical exergy, while to calculate the total exergy you can use the equation below [12].

$$E\dot{^{tot}} = E\dot{^{PH}} + E\dot{^{KN}} + E\dot{^{PT}} + E\dot{^{CH}} \quad (12)$$

However, for the PLTGU case there is no potential exergy and kinetic exergy, therefore PLTGU only uses physical exergy.

a. Physical exergy

$$E\dot{^{PH}} = \dot{m}[(h_k - h_0) - T_0(s_k - s_0)] \quad (13)$$

b. Exergy of *fuels* and products

$$E_{fuel} = E^{tot}_{inHPT} + E^{tot}_{inIPT} + E^{tot}_{inLPT} \quad (14)$$

$$E_{produk} = E^{tot}_{outHPT} + E^{tot}_{outIPT} + E^{tot}_{outLPT} + W_{STtotal} \quad (15)$$

c. Exergy destruction rate

$$E_{dest} = E_{fuel} - E_{produk} \quad (16)$$

d. exergy efficiency

$$\eta_{eksergi} = \frac{E_{produk}}{E_{fuel}} \times 100\% \quad (17)$$

2.5 Python Programming Language

The advantages of using a programming language in calculations and also graphical display are that it can speed up and ease the work of researchers and devices used for the analysis process, because with large and complex data sets it will take time to perform the calculations.

3. RESEARCH METHODS

The research was conducted in January 2023, with operational data taken from 1 to 6 January 2023, where the research was carried out, namely PLTGU PT X and focused on research on block 3 steam turbines. Like in Figure 1 below.

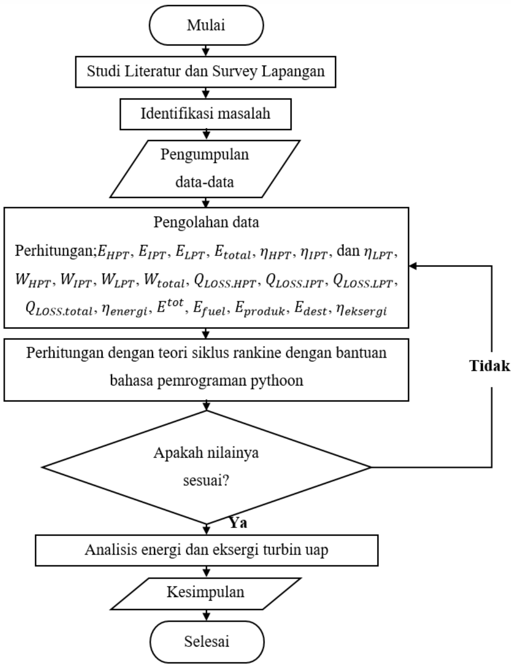

Figure 1. Research scheme

3.1 Data collection technique

a. Direct observation
b. Indirect observation
c. Study of literature
d. Interview
e. Operational data collection

4. RESULTS AND DISCUSSION

Mass flow rate of the three steam turbines, and the load of the two gas turbines from 1 to 6 January 2023.

Data processing with python is carried out in the same steps as traditional calculations as usual. The calculation begins with finding the enthalpy and entropy values, then substituted into equations 1 to 17.

4.1 Analysis and Discussion

In accordance with the theory, that the exergy value will always be higher than the energy value, because energy is part of the exergy that is utilized. Likewise, if exergy decreases, energy will also decrease. The highest energy and exergy values are in the data on January 6, 2023 , while the smallest is in the data on January 1, 2023. Like in the figure 2. below Energy vs Exergy.

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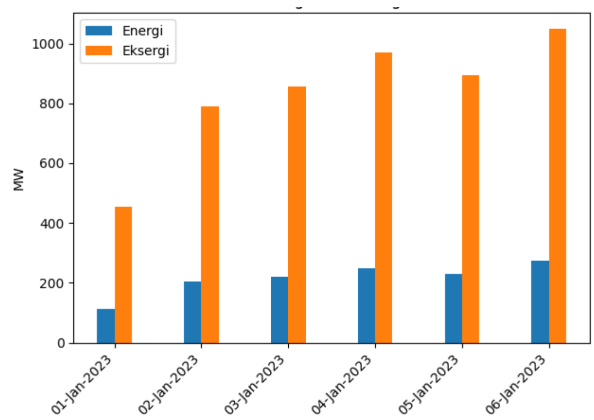

Figure 2 Energy vs exergy

The highest isentropic efficiency in the IP steam turbine data is dated January 1, 2023, this is because the inlet enthalpy is the highest compared to other data, the IP steam turbine is also the steam turbine with the most stable isentropic efficiency value . Meanwhile, the lowest isentropic efficiency is found in LP steam turbines on January 1, 2023. Like in figure 3.

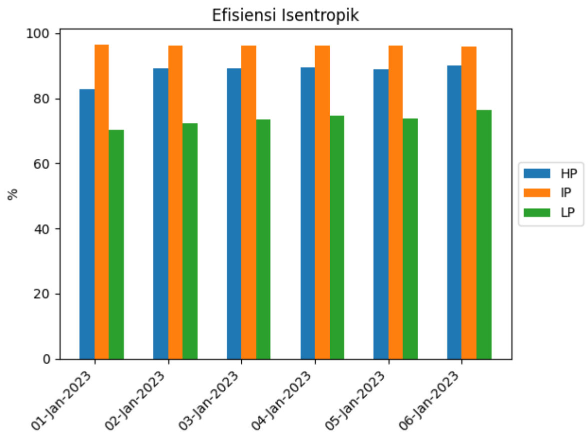

Figure 3 Efficiency vs date steam turbine

The highest work was on the HP steam turbine on January 6 2023 , while the lowest turbine work was on the LP steam turbine on January 1 2023 . Almost all of the steam turbines experienced an increase in working value, there was only one decrease on January 5. Like in figure 4.

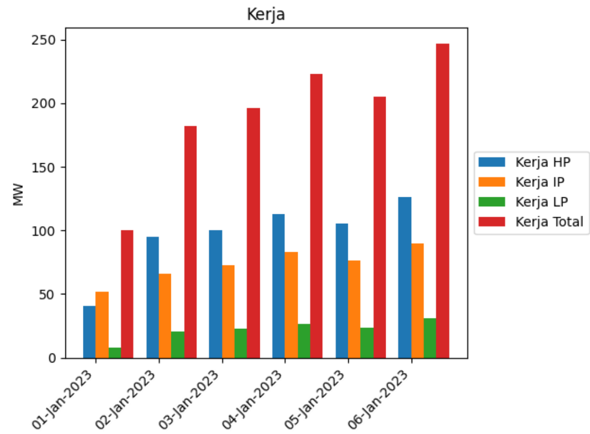

Figure 4 Work vs date steam turbine

4.2 Exergy of Fuel and Products

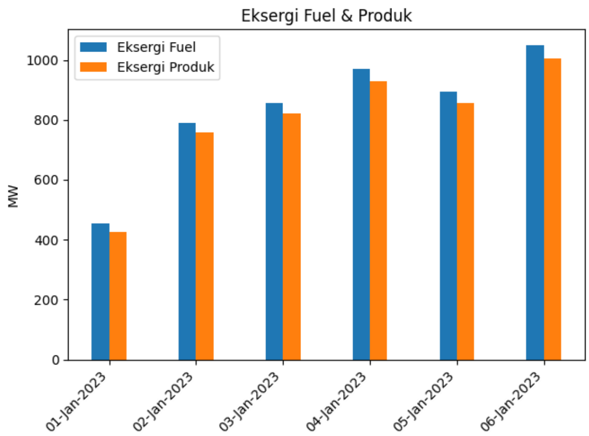

Figure 5. Exergy vs exergy product

According to the theory, the exergy of each fuel is higher than the exergy of the products. This refers to the exergy destruction rate equation. The largest exergy value of fuel and product is on data on January 6, 2023 , while the lowest value is on data on January 1, 2023. The difference in exergy values of fuel and product between commissioning data and operational data for each load is almost comparable, this is due to the in and out exergy values which do not differ much and the increase or decrease in the value of turbine work is not too significant so that it cannot display a high difference in the exergy value of fuel or product. On figure 5 Exergy vs exergy product.

4.3 Energy Loss Rate and Exergy Destruction

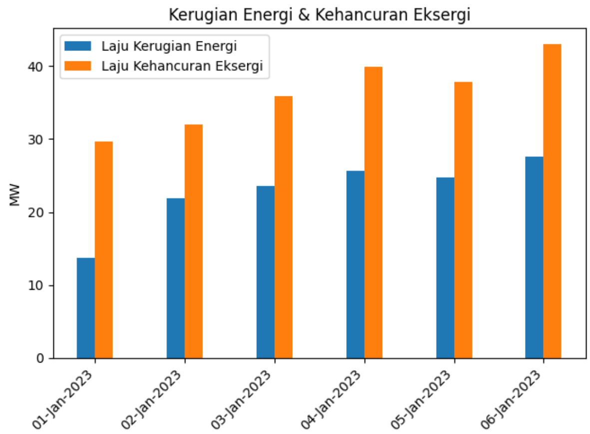

Figure 6 Energy Loss Rate vs Exergy Destruction

The rate of energy loss and exergy destruction will always follow the increase or decrease in the energy and exergy values themselves. The rate of energy loss and exergy destruction in each data always increases, except on January 5, 2023. Like in the figure 6 above.

4.4 Energy Efficiency and Exergy

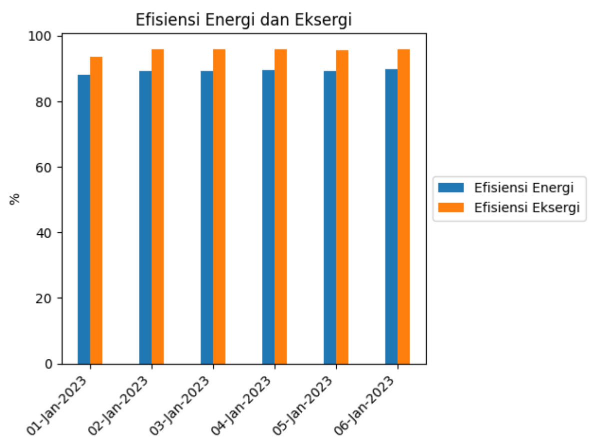

Figure 7 Energy Efficiency and Exergy

In figure 7 Exergy efficiency is higher than energy efficiency, this is related to the ratio of the amount of system exergy to exergy destruction and the energy entering the system with energy losses, the ratio of the amount of energy to energy losses is smaller when compared to the ratio of the amount of exergy of the system to the destruction of exergy. Energy efficiency increases and decreases more stable than exergy efficiency, because the increase and decrease in energy efficiency only $\pm 1\%$, while exergy efficiency $\pm 2\%$.

4.5 Use of Python in Data Processing

The first step in using a programming language to process data is to install the pyfluids *library* in the IDE, because other *libraries to* be used are already available in the IDE. Then change the operational data CSV file to *dataframe form* by making commands to read the file so that it can be operated. After that iterate over each row in *the dataframe* so that each row is subject to the same function command . Then change some of the required *input units according to the requirements of the pyfluids library*. Choose the available water fluid in pyfluids, then run the enthalpy and entropy calculations . Then *update* each column in *the dataframe* after the operational data with enthalpy and entropy values so that energy and exergy calculations can be carried out. After that energy and exergy calculations can be performed. Update *the dataframe* by entering the calculated energy and exergy values and uploading them *in the* form of the latest CSV file to make it easier to sort and display them in the form of bar graphs. There are 6 graphs made with pandas, numpy, and matplotlib *libraries* that can display changes in energy and exergy values with *commissioning data* and also operational data.

4.6 Analysis of Differences in Calculation Results

In both calculations there are differences in the results of the calculations, but the differences are very small, namely only the range $\pm 0.126782429\%$. Therefore the Python programming language can be used to process steam turbine generation data to obtain energy and exergy values.

5. CONCLUSION

Python programming language can speed up the data analysis process, with a very small deviation value. The results of the analysis showed good results, almost all of the analysis results showed an increase from the beginning of the study to the end of the study, only a slight decrease occurred, namely on 5 January 2023. This was caused by a decrease in the load value on the gas turbine, because PLTGU is a chain reaction starting from the PLTG, then the value of the results of the steam turbine analysis is related to the value at the PLTG. The increase in the value of several objects was caused by many factors, namely a good and scheduled maintenance process, a generation process that always follows procedures, the existence of several innovation programs that make the generation process work more efficiently, reduction of desalination devices, *and* changes in fuel suppliers to get better fuel. better. Although there is still a decrease, the value of all research objects with operational data shows a fair value. Therefore the steam turbine at PLTGU PT X is still feasible to operate for the next few years.

AUTHORS' CONTRIBUTIONS

"Authors' Contributions: [MUHAMMAD ALVIN JIRDAN] designed and supervised this study, conducted data analysis, and [FAHRUDIN FAHRUDIN] wrote and edited the manuscript. All authors contributed significantly to the planning, implementation, and completion of this work."

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