Simulation of Working Age Effect on the Geothermal Power Plant Generators Efficiency

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Abstract. The efficiency of the generator engine is very influential on the performance of the entire steam generating system. The efficiency is proportional to the performance of the generator engine. Also, efficiency depends on the working age of the machine, therefore, an analysis of the efficiency of the generator engines based on a certain period of time is needed. One way to find out the feasibility of a generator is by calculating the efficiency value of the generator now (actual) compared to the efficiency value of the generator at the first time the generator is operated (commissioning). Manual in analyzing efficiency calculations are quite complicated because they are concerned with steam (thermodynamic). To facilitate the calculation of the required mathematical analysis software support. This research is focused on making simulation for efficiency value based on a certain time period according to the operational age of the generator using MatLab software with the aim of more variation result and can be presented in the form of a graph is easy to understand. This result can also be made as a prediction of the feasibility of a steam generator engines. This research was conducted PLTP Kamojang, West Java, Indonesia.

1. Introduction

The energy consumption in the world is now a little over 400 EJ per year. Available energy resources in the world are large, and the energy shortage is not expected in the foreseeable future. On the other hand, most (86%) of the energy used in the world at present is coming from finite energy resources, whereas renewable energy sources are more suitable for sustainable development. The highest share of the use of renewable energy resources is in Iceland, where renewable energy comprises approximately 70% of the primary energy resources and approximately 30% is derived from fossil fuels. This unique position has been achieved by an extensive and advanced use of geothermal energy [1].

In Indonesia is very rich in geothermal energy sources, according to data sources obtained from Indonesia investment on 21 December 2017 where Indonesia is ranked third in generating energy sourced from geothermal with the amount of power generated by 1.197 Mwe. About 40% of geothermal energy reserves the world lies beneath the land of Indonesia, then the country is estimated to have the largest geothermal energy reserves in the world and therefore has a high potential for renewable energy sources. However, most of this potential has not been used. Currently, Indonesia uses only 4-5% of its geothermal capacity [2].

One of the sources of geothermal powered electricity generation in Indonesia is in the Garut area of the plant Kamojang geothermal power, which is located at 40 kilometers southeast of the city of
Bandung and 24 km northwest of the town of Garut, with a height of 1500 meters above sea level. Having air temperature peak at 15°C-25°C with an average rainfall of 2,885 mm annually [3].

Generators and turbines become a major component generation tool, where the turbine and generator function serves as a tool to convert, which serves as a driving turbine first, that converts potential energy of steam into energy kinetic and then converted into mechanical energy in the form of rotation of the turbine shaft. While the generator is a tool that serves to change the mechanical energy into electrical energy through the electric field generated due to the intersection of the lines of magnetic force lines are then cause electric lines of force GGL. Based on the main component of the generation system there is certainly an efficiency value generated by a generator. The efficiency value is determined from the value of $P_{in}$ and $P_{out}$ generated and the basis for declaring a system is said to be efficient or not to the load [4].

Therefore, this research is done in the form of efficiency analysis of Kamojang Geothermal Power Plant (PLTP). With reference to the comparison between the first times the data generator is operated in commissioning and on the actual data. This research is a form of development from previous research where the calculation of efficiency of geothermal power generator which refers to the law of thermodynamics which become the reference in determining Thus the authors try to simulate the calculations and analyze the efficiency of a system of geothermal power plant by accumulating an overall efficiency value to obtain a comparison impairment generator efficiency by using the GUI in Matlab. Data comparison will be found to efficiency values when first generator is operated and when the actual data [5].

2. Methods

This research was done at the company PT Indonesia Power UPJ Kamojang geothermal power. Figure 1 shows the flowchart groove in the execution of the research, the method described in the settlement of a simulation analysis of generator.

![Research Flowchart](image)

**Figure 1.** The research flow shows the research process starting from the determination of parameters to the data processing.

2.1. Determination of the research parameters

In this research, parameters used are turbine input and output vapor temperature, steam mass flow rate, to calculate the incoming power of the generator, and generator output power to calculate efficiency value in the generator.
The steam cycle used in this discussion is the Separated Steam Cycle, wherein geothermal power plant (PLTP) Kamojang comes out of the wellhead as a mixture of two-phase fluid (vapor phase and liquid phase). Then the first process of separation on the fluid. This is possible by passing the fluid into the separator, so that the vapor phase will be separated from the liquid phase. The vapor fraction generated from the separator is then used in the calculation of turbine power. Therefore, this energy conversion system is called the Separation Cycle of Separation. [6] Figure 2 shows the Schematic diagram of Steam Cycle Results of Separation.

![Figure 2. Schematic diagram of Steam Cycle Results of Separation.](image)

Figure 3 shows the steam cycle that occurs through the T-S chart. At point 1 geothermal fluid is a mixture of two phases. Before entering the fluid turbine undergo isenthalpic process from point 1 to point 2. At the well head known mass flow rate of fluid vapor fraction (steam quality at well head). At point 2 the fluid enters the separator, the vapor fraction enters the separator, while the water fraction is discarded. At the pressure and temperature of this turbine input is known enthalpy and entropy fluid from the steam table. Entropy at point 4 and point 5 (turbine input and output) is considered to be the same (the process occurring within an isentropic turbine). The calculation of turbine power in this system is similar to that in the Single Evaporation Cycle, the difference lies in determining the initial conditions of the fluid. At point 1 the fluid is a mixture of two phases (liquid phase and vapor phase), so the fluid enthalpy equals the sum of the enthalpy of the two phases. Furthermore, the turbine power determination procedure is the same as the calculation procedure in the Single Evaporation Cycle.

In this journal, the researcher conducts research in order to find efficiency value in Kamojang 2 PLTP generator unit, where the power generated by generator unit 2 is 55MW. Generating electrical energy in a geothermal power plant involves two energy conversions, converting steam heat energy into kinetic energy in a turbine and using a rotary generator to convert energy Data retrieval mechanical turbine into electrical energy [7]. There are several criteria in determining efficiency value of a generator which in discussion of this paper is the vapor temperature, and flow rate of vapor that enter into generator where this become main parameter in determining power coming in generator. In this discussion also
thermodynamic table into a reference where in determining the power into the generator through some calculation enthalpy and entropy incoming steam temperature \[8\].

Data collection was performed at the thermal power plants of the earth where the data taken is the data commissioning which the data were first generator operated with regard to steam and speed of the flow of steam into a turbine which is converted into a form of mechanical energy into and become the power to drive the generator, Where data is obtained from the commissioning of the generator unit 2 PLTP Kamojang, 1987.

Besides commissioning of data required, the actual data was needed to determine the percentage decrease in the efficiency of the generator as a result of the influence of the working age generator actual data is the data obtained in June 2017. In the table 1 and table 2 below the commissioning of data and actual data obtained.

2.2. Data processing
Data processing is done by using the formula and based on thermodynamic table with the result of data that has been in can with the following flow:

2.2.1. Determine enthalpy and entropy of the incoming and outgoing steam turbines on the thermodynamic table.

**Table 1.** The enthalpy and the entropy of a temperature based on the thermodynamic table.

| Enthalpy | Entropy |
|----------|---------|
| hf = | sf = |
| hfg = | sfg = |
| hg = | sg = |

A temperature has a value of enthalpy and entropy where the value is already on the Table 1 thermodynamic so, we can simply look at the tables.

2.2.2. Finding quality steam dryness fraction (X).

\[ x = \frac{s_{fg1}}{s_{fg2}} \]  

Information

\[ x \] = Quality steam dryness fraction
\[ s_{fg1} \] = Value of entropy evap when vapors enter
\[ s_{fg2} \] = Value of entropy evap when the steam out

Evap entropy values can be seen in the table so we stayed split thermodynamic entropy values entered by the entropy evap out

2.2.3. Finding value on exit saturated steam turbine.

\[ h_{g3}=hf2+x\times h_{fg2} \]  

Information

\[ h_{g3} \] = Value of saturated vapor as it exits the turbine
\[ x \] = Quality steam dryness fraction
\[ hf2 \] = The value of the enthalpy of liquid when the steam out
\[ h_{fg2} \] = The value of the enthalpy evap when the steam out

2.2.4. Searching for businesses that do steam turbine (W).

\[ w=\Delta h=h_{g1}-h_{g3} \]  

Information

\[ \Delta h \] = Change of enthalpy
2.2.5. Looking for steam turbine power (P).

\[ P_{\text{turbine}} = m \times w \]  \hspace{1cm} (4)

Information

- \( P_{\text{turbine}} \) = Power the steam turbine
- \( m \) = Mass flow rate of steam
- \( w \) = Efforts turbine

2.2.6. Calculating unit 2 generator efficiency (based on data commissioning & actual data) [9].

\[ \eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100\% \]  \hspace{1cm} (5)

Information

- \( \eta \) = efficiency generator
- \( P_{\text{out}} \) = power out on the generator
- \( P_{\text{in}} \) = power in on the generator

Data processing is done by manual calculation and calculation using software, where software used is MatLab R2015b software using Graphical Using Interface method on its calculation.

2.3. Graphical using interface

GUI is a graphical display on one or more windows that contain controls, components that are called, which allows users to interactive tasks. Users do not have to write a script or typing commands on the command line to complete the task. Unlike the encoding program to complete the task, the user does not need to understand the details of how the task is done. GUI components can include menus, toolbars, push buttons, radio buttons, list boxes, and slider-just to name a few. GUI created using MATLAB® tool can also do all kinds of computing, read and write data files, communicate with other GUI, and displays the data as a table or as a plot [10].

In software design simulation of GUI calculations in matlab R2015b, we need to know first [11]. In calculating simulation design using Graphical Using Interface there are some tools used in displaying the programs that we want to show, tools used in this final project work described in the Figure 4.

![Figure 4. Schematic display of GUI program.](image-url)
In this project the tools used are push button, statistic text, and edit text, where in the previous explanation explains that in this GUI software does not require script command in finishing task because automatically format of command has been input on script page but, in the use of tools there are tags and strings that need to be set to call the command when one of the tools want to be done or operated, and the operation function we want to do, its example as in the push button tool we tag and the string we want to write. And the variables we will input need to be in the settings will be operated like what, in the case of generator efficiency calculation generator equations call the pushbutton tag so that when pushbutton push button on the input into the string Pin and Pout can operate according to the input command. Schematic setting tool on the GUI is shown in Figure 5.

![Figure 5. Schematic setting tool on the GUI](image)

The tag in question is the identity tool in the GUI program, functions as a tag to be included into the program call. After the design that we want to have finished we do, we live operate simulation by clicking the play button on the top of the GUI display so that it will appear graphical display that want to show with various graphics functions that want to be displayed, in this study graphic display wanted is as shown in Figure 6.

![Figure 6. GUI simulation display](image)

3. Results and discussions
Analysis is done by taking the data commissioning and actual data in the can from the data retrieval results in PLTP kamojang on 11 June 2017, where the data commissioning and actual data in can be described in the table 2 below:

| Table 2: Commissioning data [12] |
|----------------------------------|
| Data | Value |
|------|-------|
| Pin  |       |
| Pout |       |

After the calculation of data in Table 2 then the efficiency value of each hour can be determined by using the calculation model that has been described based on thermodynamic calculation efficiency value of generator unit 2.
Table 2. Data commissioning on August 7, 1987.

| Hour   | Generator power (MW) | Steam Temperature in (°C) | Steam Temperature out (°C) | Steam Mass Flow rate (tons / hour) |
|--------|----------------------|---------------------------|----------------------------|-----------------------------------|
| 17:00  | 52.4                 | 165                       | 64                         | 410                               |
| 18:00  | 55                   | 165                       | 56                         | 410                               |
| 19:00  | 55                   | 165                       | 56                         | 410                               |
| 20:00  | 55                   | 166                       | 56                         | 410                               |
| 22:00  | 54.9                 | 165                       | 56                         | 410                               |
| 24:00  | 54.8                 | 165                       | 56                         | 410                               |

Table 3. Manual calculation results P input.

| Hour | Turbine power (kJ/s) | Generator Efficiency (%) |
|------|----------------------|--------------------------|
| 17:00| 102.339.15           | 51                       |
| 18:00| 112.731,44295        | 49                       |
| 19:00| 112.731,44295        | 49                       |
| 20:00| 112.849,89895        | 49                       |
| 22:00| 112.731,44295        | 49                       |
| 24:00| 112.731,44295        | 49                       |

Table 3 is Manual calculation results P input. After the next manual calculation we compare it by using the simulation calculation by input power value and generator output power in simulation that has been made, the simulation result shown in Figure 7 where the efficiency value shown by matlab simulation with GUI method, efficiency value in show by simulation is the result of data on the calculation at 17:00.

Figure 7. GUI simulation results based on commissioning data.

In addition shown by the GUI method shown also the graph of efficiency values shown by Figure 8 where there is a decrease in efficiency over time, the decrease is caused by a decrease in output power output of the generator due to the outflow vapor process that changes the value of the vapor enthalpy on the thermodynamic table, seen efficiency value at 17:00 hours decreased at 18:00.

Figure 8. Graph of generator efficiency based on commissioning data.
3.2. Actual data [13]

Table 4. Actual data of PLTP Kamojang on 11 June 2017.

| Hour   | Generator power (MW) | Steam Temperature in (°C) | Steam Temperature out (°C) | Steam Mass Flow rate (tons / hour) |
|--------|----------------------|---------------------------|---------------------------|------------------------------------|
| 00.00  | 56.1                 | 164.4                     | 49                        | 423                                |
| 01.00  | 56.1                 | 164.5                     | 49                        | 425                                |
| 02.00  | 56.2                 | 164.5                     | 49                        | 425                                |
| 03.00  | 56.3                 | 164.5                     | 48.5                      | 425                                |
| 04.00  | 56.4                 | 164.5                     | 48.5                      | 418                                |
| 05.00  | 56.1                 | 164.3                     | 48.5                      | 414                                |
| 06.00  | 56                  | 164.5                     | 48.5                      | 416                                |
| 07.00  | 56                  | 164.5                     | 48.5                      | 416                                |
| 08.00  | 55.8                 | 164.6                     | 48.5                      | 423                                |
| 09.00  | 55.6                 | 165                       | 48.5                      | 419                                |
| 10.00  | 55.5                 | 164.3                     | 48.5                      | 422                                |
| 11.00  | 54.9                 | 164.6                     | 48.5                      | 418                                |
| 12.00  | 54.8                 | 164.4                     | 49                        | 422                                |
| 13.00  | 54.9                 | 165                       | 49                        | 421                                |
| 14.00  | 54.7                 | 165                       | 49                        | 419                                |
| 15.00  | 54.6                 | 164.6                     | 49.5                      | 420                                |
| 16.00  | 54.8                 | 165                       | 48                        | 414                                |
| 17.00  | 54.7                 | 164.8                     | 48                        | 415                                |
| 18.00  | 54.8                 | 164.4                     | 48.5                      | 419                                |
| 19.00  | 55                  | 164.7                     | 48.3                      | 413                                |
| 20.00  | 55.2                 | 164.6                     | 49                        | 421                                |
| 21.00  | 55.4                 | 164.6                     | 49                        | 421                                |
| 22.00  | 55.4                 | 164.6                     | 50                        | 424                                |
| 23.00  | 55.6                 | 164.2                     | 49.5                      | 424                                |
| 24.00  | 55.6                 | 164.4                     | 49.5                      | 428                                |

Table 4 is actual data of PLTP Kamojang on 11 June 2017. After calculation of data in Table 5 then the efficiency value every hour can be determined by using the calculation model that has been in paparka based on thermodynamic calculation efficiency value of generator unit 2.

Table 5. Manual calculation results P input and generator efficiency based on actual data.

| Hour   | Turbine Power (kJ/s) | Generator Efficiency (%) |
|--------|----------------------|--------------------------|
| 00.00  | 123.97               | 45                       |
| 01.00  | 124.556              | 45                       |
| 02.00  | 124.556              | 45                       |
| 03.00  | 124.556              | 45                       |
| 04.00  | 122.505              | 46                       |
| 05.00  | 121.332              | 46                       |
| 06.00  | 121.918              | 46                       |
| 07.00  | 121.918              | 46                       |
| 08.00  | 124.556              | 44                       |
| 09.00  | 122.848              | 45                       |
| 10.00  | 123.677              | 45                       |
| 11.00  | 122.505              | 45                       |
| 12.00  | 123.677              | 44                       |
| 13.00  | 123.434              | 44                       |
| 14.00  | 122.848              | 44                       |
| 15.00  | 123.091              | 44                       |
| 16.00  | 121.382              | 45                       |
| 17.00  | 121.625              | 45                       |
| 18.00  | 122.798              | 44                       |
| 19.00  | 121.039              | 45                       |
| 20.00  | 123.384              | 45                       |
| 21.00  | 123.384              | 45                       |
| 22.00  | 121.193              | 46                       |
| 23.00  | 124.263              | 46                       |
| 24.00  | 125.435              | 44                       |

Average 44.96
After the next manual calculation we compare using the simulation calculation by input power value and generator output power in simulation that has been made, the simulation result shown in Figure 9 below where the value of efficiency shown by matlab simulation with GUI method, efficiency value in show by simulation is the result of data on the calculation at 13:00.

![GUI simulation results based on actual data](image)

**Figure 9.** GUI simulation results based on actual data.

In addition shown by the GUI method shown also the graph of efficiency values shown by Figure 10 where there is fluctuation rise and fall of efficiency over time, the decrease is caused by a decrease in output power output from the generator due to the outflow vapor process that changes the value of vapor enthalpy on tables of thermodynamics, seen efficiency value at 17:00 hours decreased at 18:00. And fluctuations gradually rose by 19:00 hours and the peak of highest efficiency was at 22:00 on the chart with efficiency rating reaching 46%.

![Graph of generator efficiency based on actual data](image)

**Figure 10.** Graph of generator efficiency based on actual data.

If compared to the data commissioning chart with actual data then Figure 11 shows the difference graph where the visible difference can be caused by the influence of working age on the generator where the value of efficiency in the commissioning data has decreased up to the last actual data obtained.

![Graph of comparison between efficiency value based on commissioning data and actual data](image)

**Figure 11.** Graph of comparison between efficiency value based on commissioning data and actual data.
4. Conclusions
Based on the research that has been done there is a decrease in the number of efficiency presentation of generator unit 2 PLTP kamojang where the decline occurs within the working age of the generator for approximately 30 years, where the impairment of efficiency is obtained from the comparison of 49.3% commissioning average data value, average efficiency of actual data is 44.96%, which decreased efficiency by 4.34%.

The difference in the difference between the efficiency of the generator when first generated with the actual data, has a fairly large difference, this is also affected by the age of work and quality of maintenance, where the normal generator engine to replace the unit every 35 years, but it can be said maintenance at PT Indonesia Power good with duration 30 years working age decrease efficiency of generator only decrease 4.34% only.

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