# Heat Rate Gap and Cost Analysis Due to Increase of Condenser Pressure in A 660 MW Combined Cycle Power Plant

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***Abstract*—A condenser is one of the main equipment in a Combined Cycle Power Plant (CCPP) cooling system which has a great influence on steam turbine output and thermal efficiency of the whole power plant as well. The objective of this study is to analyze the effect of increase in condenser pressures on the heat rate and electricity production costs. The primary data is acquired from the DCS. These data are then compared to those of the best performance operating data. The differences of these two data of 23 parameters, are then integrated with the impact factor to gain the heat rate loss. Based on the heat rate loss, then the cost of electricity production is established accordingly. The study concludes that the increase of condenser pressure from 2.41 inHgA to 2.82 inHgA results in increase of plant heat rate 19.55 kcal/kWh. The 5 great parameters to contribute to this loss are: HP and LP steam flows, condenser pressure, stack temperatures of HRSG 1.3 and 1.2. Meanwhile, the cost of production rises up from 751 IDR/kWh to 805 IDR/kWh.***

***Keywords*— Condenser, CCPP, Plant Heat Rate, Production Cost, Impact Factor.***

## I. INTRODUCTION

Combined Cycle Power Plant (CCPP) is a combination of gas turbine power plant and steam turbine power plant. CCPP has a lower heat rate compared to those of steam turbine or simple cycle gas turbine, therefore the performance of a CCPP is better[1]. In addition, CCPP has a fast ramp rate that functioned as a peak load power plant.

A steam condenser plays an important role in steam power plants[2]. Therefore, the operation of the condenser under optimum operating conditions is essential to obtain maximum efficiency of the generating unit and minimum heat rate[3]. However, in reality, there are many constraints that tend to lead to changes in operating conditions of the design. If the condenser operating conditions change from the design, then the performance of the power plant (power output and heat rate) will also change from the design performance value[4]. Many papers have examined the effects of changes in operating parameters such as cooling water inlet temperature and the cooling water rate on condenser performance[5]–[7]. An increase in cooling water temperature and a decrease in cooling water rate may cause an increase in condenser pressure. Consequently, with the increase in condenser pressure causes the heat rate to increase and the power of the generator output decreases[8].

Currently, electricity conditions in Java-Bali systems have more than enough electricity reserves. So the Load Dispatcher will select a power plant of lowest operating cost to operate. Thus, power companies are required to try to lower the cost of production, such that the selling price of electricity is as low as possible. One measure to do is to map all the sources that may the increase production cost, increase in heat rate among others.

The objective of this study is to analyze the effect of increase in condenser pressures on the heat rate. It will also analyze the increase in electricity production costs due to an increase in heat rate. The case study was conducted on combined cycle power plant in Java that have an installed capacity of 660 MW which consists of 3 units of gas turbine, 3 units of heat recovery steam generator, and 1 unit of steam turbine. The main fossil fuel is natural gas or fuel oil type high speed diesel (HSD). The average electricity production per year is 4.393 GWh, which is supplied to the Java-Bali interconnection system.

## II. METHOD

This study is carried out only on base load conditions. The primary data as existing data is acquired from the DCS. These data are then compared to those of the best performance operating data. These differences between those two data, consists of 23 parameters, are then integrated with the impact factor to gain the heat rate loss[9]. The increase in electricity production cost is calculated based on the increase of heat rate with the price of natural gas and the amount of electricity production.

## III. RESULTS AND DISCUSSION

**Heat Rate Analysis.** Comparison of existing data and best performance operating data, is shown in **Table 1**. The comparison result is calculated based on the impact factor of each parameter to obtain the Pareto heat rate gap analysis as shown in **Figure 2**. Many factors can cause a change in the plant heat rate, but the parameters evaluated are representative because the value of other losses is relatively small at 1.74%.

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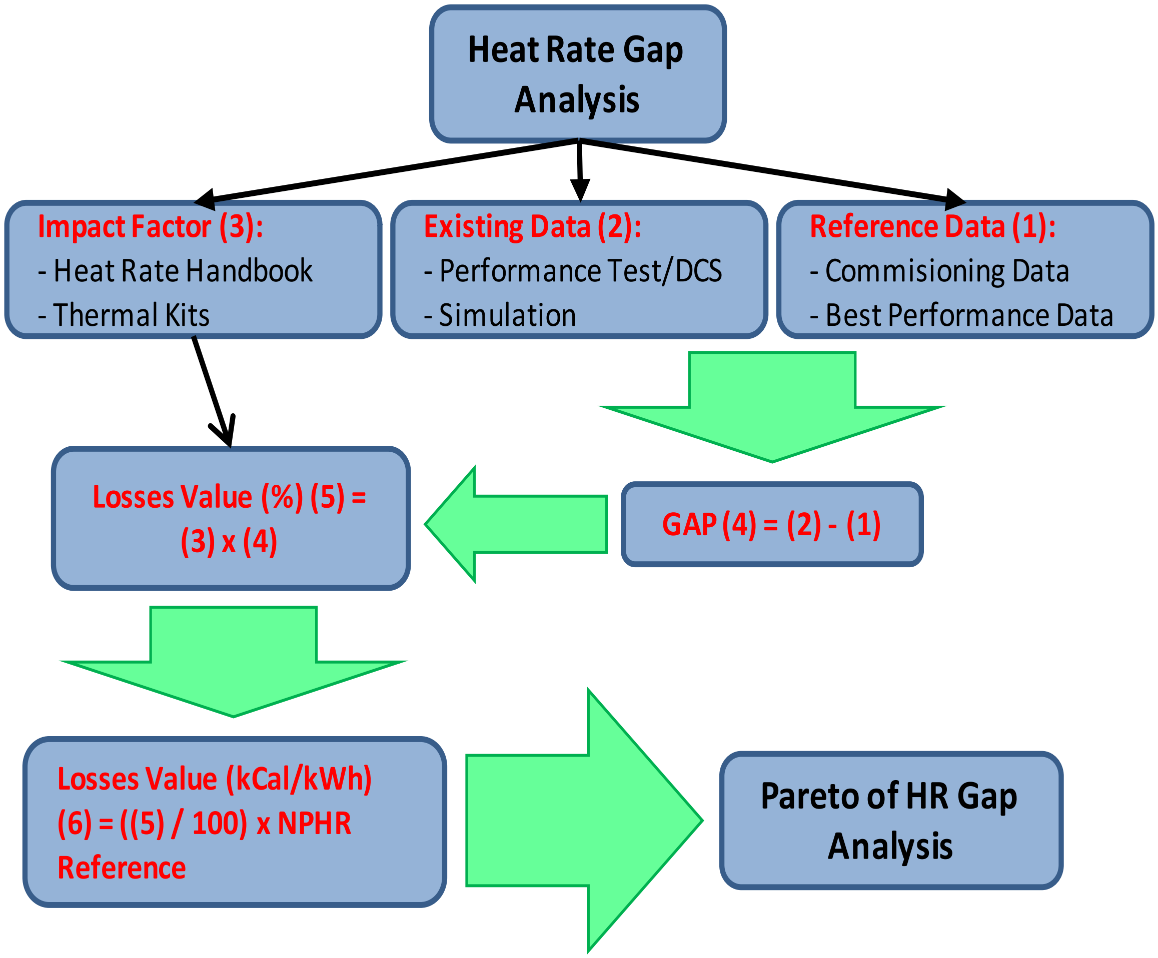


**Figure. 1.** Flow Diagram of Heat Rate Gap Analysis.

**Figure 3** illustrates the percentage of heat rate losses per equipment that contributes 90% of the total heat rate losses of the plant. The increase in condenser pressure contributed to the third largest heat rate losses of 14% to a value of 19.55 k Cal / kWh as shown in Table 1. While the 5 great parameters to contribute to this loss are: HP and LP steam flows, condenser pressure, stack temperatures of HRSG 1.3 and 1.2.

**Cost Analysis.** Natural gas price used in this power plant amounted to USD 7.46 per mmbtu or equivalent to 0.4 IDR/kCal (based on exchange rate of IDR 13370 / USD). So the electricity production costs of existing data and the best performance operating data:

Existing data = 2013.18 kcal/kWh x 0.4 IDR/kCal
= 805 IDR/kWh

The best performance operating data
= 1877.99 kCal/kWh x 0.4 IDR/kCal
= 751 IDR/kWh

The electricity production costs rise up from 751 IDR/kWh to 805 IDR/kWh. Thereby increasing the cost of electricity production by 54 IDR/kWh. The average electricity production at base load condition per year is 390,162,000 kWh, so the annual increase in electricity production costs is:

The annual increase = 54 IDR/kWh x 390162000 kWh
= IDR 21,068,748,000
= IDR 21.07 billion

The increase in electricity production costs is due to the heat rate loss of previously analyzed parameters. The 5 great parameters to contribute to this increase is shown in Table 2.

This value is a minimum increase in production cost, because the evaluation is only done for base load conditions. The increase in production cost will be higher if the CCPP is a base load power plant.

TABLE 1
PERFORMANCE TEST RESULTS AND REFERENCES DATA

| Parameters | | Existing Data | Reference | Losses (%) | Losses (kCal/kWh) |
|---|---|---|---|---|---|
| GT Load (MW) | | | | | |
| | GT 1.1 | 96.07 | 96.05 | -0.002 | -0.040 |
| | GT 1.2 | 97.62 | 98.41 | 0.072 | 1.346 |

| | | | | | |
|---|---|---|---|---|---|
| | GT 1.3 | 96.04 | 96.71 | 0.071 | 1.333 |
| Inlet Press. Drop (inch H2O) | | | | | |
| | GT 1.1 | 1.18 | 1.46 | -0.030 | -0.569 |
| | GT 1.2 | 1.57 | 0.98 | 0.065 | 1.220 |
| | GT 1.3 | 0.79 | 0.59 | 0.022 | 0.407 |
| Comp. Inlet Temp. (degF) | | | | | |
| | GT 1.1 | 82.68 | 83.41 | -0.029 | -0.549 |
| | GT 1.2 | 81.37 | 82.85 | -0.059 | -1.111 |
| | GT 1.3 | 81.42 | 84.09 | -0.107 | -2.007 |
| STG Load (MW) | | 199.19 | 214.02 | | |
| Auxiliary Power (MW) | | 10.35 | 10.31 | 0.009 | 0.175 |
| Condenser vaccum (inch HgA) | | 2.82 | 2.41 | 1.041 | 19.549 |
| HP Steam Flow (Tph) | | 583.06 | 609.77 | 2.410 | 45.266 |
| HP Steam Pressure (Psi) | | 985.19 | 1013.82 | 0.115 | 2.151 |
| HP Steam Temperature (degF) | | 929.48 | 914.04 | -0.232 | -4.350 |
| LP Steam Flow (Tph) | | 260.74 | 276.65 | 1.435 | 26.957 |
| LP Steam Pressure (Psi) | | 67.47 | 75.56 | 0.032 | 0.608 |
| LP Steam Temperature (degF) | | 317.59 | 349.77 | 0.483 | 9.067 |
| HP ST Efficiency (%) | | 94.22 | 95.87 | 0.297 | 5.578 |
| LP ST Efficiency (%) | | 79.20 | 76.91 | -0.252 | -4.731 |
| Make Up Water (Tph) | | 13.00 | 12.16 | 0.202 | 3.786 |
| Stack Temperature (degF) | | | | | |
| | HRSG 1.1 | 257.27 | 245.94 | 0.283 | 5.318 |
| | HRSG 1.2 | 278.50 | 258.85 | 0.491 | 9.222 |
| | HRSG 1.3 | 266.63 | 236.36 | 0.757 | 14.209 |
| Heat Rate (kcal/kWh) | | 2013.18 | 1877.99 | 7.199 | 135.189 |
| Sub Total Losses | | | | 7.073 | 132.833 |
| Other Losses | | | | 0.125 | 2.357 |
| Total Losses | | | | 7.199 | 135.189 |

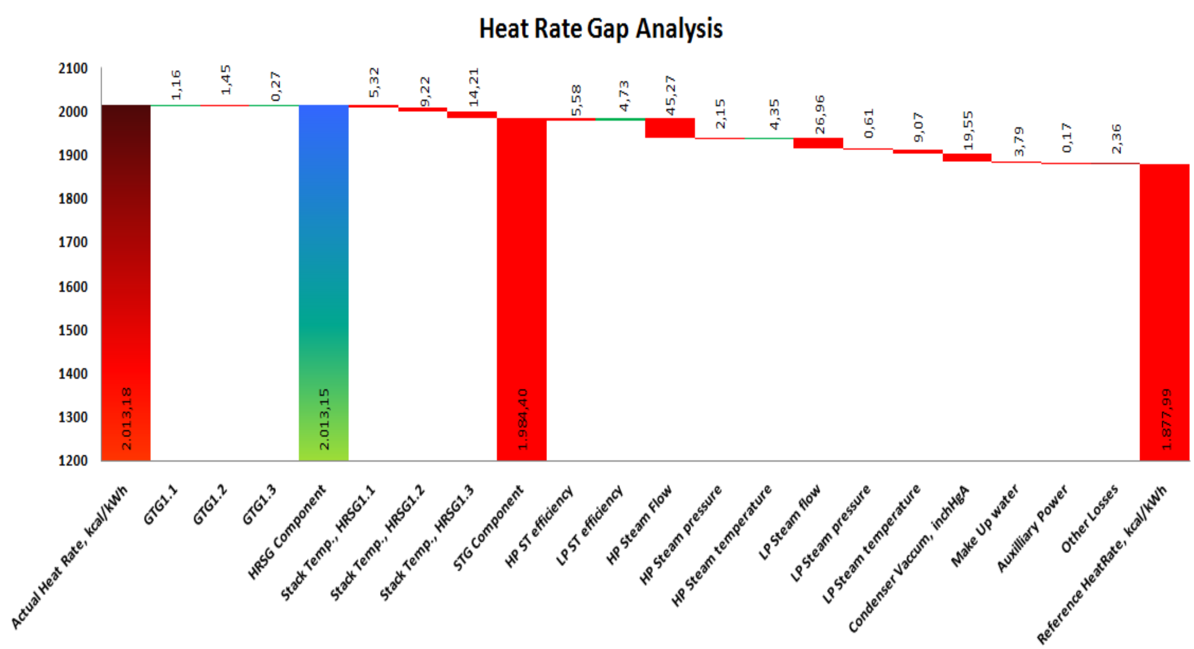


**Figure. 2.** Pareto Heat Rate Gap Analysis

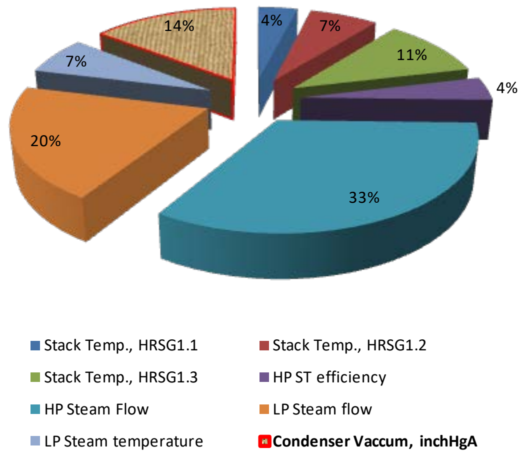


**Figure 3.** Percentage of Heat Rate Losses

TABLE 2
THE 5 GREAT PARAMETERS TO CONTRIBUTE TO THE INCREASE IN PRODUCTION COSTS

| Parameters | Heat Rate Loss | The Increase in Production Costs | |
|---|---|---|---|
| | (kcal/kWh) | (IDR/kWh) | Annual (IDR x billion) |
| HP steam flow | 45.27 | 18.11 | 7.06 |
| LP steam flow | 26.96 | 10.78 | 4.21 |
| Condenser Pressure | 19.55 | 7.82 | 3.05 |
| Stack temperature of HRSG 1.3 | 14.21 | 5.68 | 2.22 |
| Stack temperature of HRSG 1.2 | 9.22 | 3.69 | 1.44 |

## IV. CONCLUSION

Many factors cause plant heat rate changes in CCPP and most of the causes are on the side of the steam cycle. Some important things obtained from the analysis and evaluation are as follows:

1. The evaluated operating parameters represent the total increase of plant heat rate since the value of uncalculated loss is relatively small only 1.74%.
2. Heat rate loss due to the increase in condenser pressure is significant which has a value of 14% of the total plant heat rate loss.
3. Heat rate loss due to increase in condenser pressure by 19.55 kCal/kWh and led to an increase in annual electricity production costs of IDR 3.05 billion.
4. The electricity production cost of existing data rise up from 751 IDR/kWh to 805 IDR/kWh compared to the best performance operating data.
5. The 5 great parameters to contribute in the heat rate loss and increased production costs are: HP and LP steam flows, condenser pressure, stack temperatures of HRSG 1.3 and 1.2.

## ACKNOWLEDGMENTS

Authors gratefully acknowledge the staff of Mechanical engineering department of Institut Teknologi Sepuluh Nopember for adequate support and PT Pembangkitan Jawa Bali for permission of technical data and providing information for practical aspects.

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