Simulation of Effects Off Service Closed Feedwater Heater on Steam Power Plant Performance Using Cycle Tempo 5.0

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Abstract. Steam power plant needs three important things in its operation, they are safety, reliability, and efficiency. Steam power plant efficiency can be elevated by installing regenerative feedwater heater. Feedwater heater is used to increase the temperature of water needed for combustion process in the boiler, therefore minimizing the fuel used in boiler. Case study is taken from PT. PJB UP Muara Karang Steam Power Plant unit 4 and 5. HPH 4 off service in August 2018 caused thermal efficiency drop about 1.86 % from the previous month. The same case was found in January 2019, in which HPH F off service caused 0.68 % from the previous month. This study’s aim is to find out the effect of off service closed feedwater heater to steam power plant performance using Cycle Tempo 5.0. Steam power plant unit 5 with 172 MW load is modelled on Cycle Tempo. Validation is done by comparing some parameter of simulation result to performance test result with 5% error tolerance. Few variation off service feedwater heater conditions are done by regulating valve for line bypass in order to set feedwater flow into tubes as well as drain flow. NPHR analysis is done by gathering net power and heat needed in boiler for each variation. The result obtained from this study shows that off service feedwater heater cause NPHR enhancement. The highest NPHR increase is achieved when HPH F is on off service condition, with value about 30.58 kCal/kWh. Off service HPH has bigger effect on NPHR increase than LPH on the same condition. Steam power plant efficiency increase continuously with the greater amount of operating feedwater heater. 3 LPH and 2 HPH usage on steam power plant with 172 MW load is assessed as adequate efficient, with all feedwater heater operating at 33.39 %.

Keywords: Cycle Tempo 5.0, NPHR, Steam Power Plant, Regenerative Feedwater Heater

1. INTRODUCTION
PLTU 45 PT. PJB UP Muara Karang has two types of closed feedwater heaters based on the source of hot fluid used. Low Pressure Heater (LPH) utilizes low pressure turbine extraction steam as a source of heat. Whereas the High Pressure Heater utilizes steam extraction from high pressure turbines as heating fluid. Both types of feedwater heaters have a function to improve the efficiency of power plants. When the operation of the feedwater heater show abnormalities, the performance of a power plant also can be disrupted.
From the figure above, it is seen that the HPH E PLTU unit 4 of PT. PJB UP Muara Karang off service in August 2018, consequently the thermal efficiency decreased by 1.86% from the previous month. Whereas in January 2019 the HPH F was off service, causing the thermal efficiency of the plant to decrease by 0.68%. The problem of HPH off service is usually due to a leak. The malfunctioning of HPH causes heat requirements to produce superheated steam in the boiler to be greater than when HPH was still functioning. Based on these problems, this paper is compiled to determine the effect of off service feed water heater on the performance of steam power plants.

2. BASIC THEORY AND METHODOLOGY

2.1. Steam Power Plant With Closed Feedwater Heater

One of the ideal Rankine Cycle modification methods to improve system efficiency is by heating up feedwater regeneration. The working principle of a feedwater heater is to heat the feed water before it is heated in the boiler by using turbine extraction steam. The use of extraction will reduce the work of turbine. However if the feed water heater is able to increase the temperature of the water before it is heated in the boiler, it will reduce the needed heat by the system to produce steam. Automatically it also reduces fuel consumption. PLTU has several main components including turbines, boiler, condenser, and pumps.

1. Turbine

\[ \frac{dE}{dt} = Q_{cv} - \dot{W}_t + \dot{m}(h_1 - h_2 + \frac{v_1^2}{2} + \frac{v_2^2}{2} + g(z_1 - z_2)) \]

2. Boiler

\[ Q_{in} = Q_{cv} = \dot{m}(h_o - h_i) \]
3. Condenser

\[ Q_{\text{out}} = Q_{\text{cv}} = \dot{m}(h_i - h_o) \]  

4. Pump

\[ \frac{dE_c}{dt} = Q_{\text{cv}} - W_p + \dot{m} \left[ h_o - h_i + \frac{v_i^2}{2} + g(z_o - z_i) \right] \]

5. Closed Feedwater Heater

\[ 0 = y(h_{u\text{in}} - h_{u\text{out}}) + (h_i - h_o) \]

6. Calculation Of Efficiency

Cycle efficiency can be calculated by comparing the net power generated by the cycle compared with the heat given in the boiler.

\[ \eta = \frac{W_{\text{net}}}{m} \frac{W_p}{q_{\text{in}}} \]

7. Calculation Of Heat Rate

The heat rate states the amount of energy added to a system through heat transfer to produce a unit of work output. Nett Plant Heat Rate (NPHR):

\[ NPHR = \frac{\dot{m}_{\text{fuel}} \times LHV}{\text{Gross Generator Output} - \text{Aux. Consumption}} \]
Based on figure 2, PLTU 5 modeling is made in the tempo cycle software with the following scheme:

The next step is to run Power plant modeling in the cycle tempo 5.0 software so that there are no errors and warnings appear (convergent).

After convergent simulation results are obtained in the form of properties at each state level, absorbed power (Total Q), gross power, net power, auxiliary power consumption, efficiency, and graph T-s diagram.
Figure 4. T-s diagram PLTU #5 on cycle tempo 5.0

The T-S diagram above is obtained from the simulation results using cycle tempo 5.0 software based on the actual data of the existing PLTU Unit 5 at 172 MW. It appears that the process that occurs in a cycle is not an ideal process, where the process of compression and expansion does not occur isentropically so it causing losses.

The final step is to carry out the validation process by comparing the simulation results using the cycle tempo 5.0 software with the performance test data as a reference with deviation permissible error at 5%.

Table 1. Validation of PLTU #5 simulation results using cycle tempo 5.0

| Parameter                  | Unit       | Perf. Test | Simulasi | Error   | Judgement |
|----------------------------|------------|------------|----------|---------|-----------|
| Eff Thermal                | %          | 33.46      | 33.397   | 0.19    | Valid     |
| NPHR                       | kcal/kWh   | 2569.71    | 2574.64  | 0.19    | Valid     |
| GPHR                       | kcal/kWh   | 2443       | 2526.93  | 3.44    | Valid     |
| Auxiliary Power Consumption Generator Output | kW        | 172600     | 172000   | 0.35    | Valid     |
| Wnetto                     | kW         | 164100     | 168812.58| 2.87    | Valid     |
| Combustion heat            | kcal/hr    | 421689122  | 434632376.3| 3.07 | Valid     |
| Main Steam Flow            | ton/h      | 514.2      | 535.03   | 4.05    | Valid     |
|                           | kg/s       | 142.833    | 148.619  | 4.05    | Valid     |
| LPH A Water Outlet Temp.   | deg C      | 72         | 74.65    | 3.68    | Valid     |
| LPH B Water Outlet Temp.   | deg C      | 100        | 100.26   | 0.26    | Valid     |
| LPH C Water Outlet Temp.   | deg C      | 130        | 125.84   | 3.20    | Valid     |
| Deaerator Water Outlet Temp.| deg C  | 157        | 160.5    | 2.23    | Valid     |
| HPH E Water Outlet Temp.   | deg C      | 194        | 192.23   | 0.91    | Valid     |
| HPH F Water Outlet Temp.   | deg C      | 235        | 235.05   | 0.02    | Valid     |

| Rata - Rata | 2.04 | Valid |
Based on the table above, almost all parameters have an error deviation of less than 5%. So it can be concluded that the system built on simulation is VALID. In this paper, several variations of closed feedwater heater operations are carried out:

Table 2. Variation of off service feed water heater variation

| Variasi | LPH A | LPH B | LPH C | HPH E | HPH F |
|---------|-------|-------|-------|-------|-------|
| 1       | 1     | 1     | 1     | 1     | OFF   |
| 2       | 1     | 1     | 1     | 1     | OFF   |
| 3       | 1     | 1     | 1     | 1     | OFF   |
| 4       | 1     | 1     | 1     | 1     | OFF   |
| 5       | 1     | 1     | 1     | 1     | OFF   |
| 6       | 1     | 1     | 1     | 1     | OFF   |

Table 3. Variation of off service high pressure heater

| Variasi | HPH E | HPH F |
|---------|-------|-------|
| 1       | OFF   |       |
| 2       | OFF   |       |
| 3       | OFF   |       |
| 4       | OFF   | OFF   |

Table 4. Variation of off service lph vs hph

| Variasi | LPH A | LPH B | LPH C | HPH E | HPH F |
|---------|-------|-------|-------|-------|-------|
| 1       | 1     | 1     | 1     | 1     | OFF   |
| 2       | 1     | 1     | 1     | 1     | OFF   |
| 3       | 1     | 1     | 1     | 1     | OFF   |
| 4       | 1     | 1     | 1     | 1     | OFF   |
| 5       | 1     | 1     | 1     | 1     | OFF   |
| 6       | 1     | 1     | 1     | 1     | OFF   |

Table 5. Variation of number operated closed feedwater heater

| Variasi | LPH A | LPH B | LPH C | HPH E | HPH F |
|---------|-------|-------|-------|-------|-------|
| 1       | OFF   | OFF   | OFF   | OFF   | OFF   |
| 2       | OFF   | OFF   | OFF   | OFF   | OFF   |
| 3       | OFF   | OFF   | OFF   | OFF   | OFF   |
| 4       | OFF   | OFF   | OFF   | OFF   | OFF   |
| 5       | OFF   | OFF   | OFF   | OFF   | OFF   |
| 6       | OFF   | OFF   | OFF   | OFF   | OFF   |

3. RESULT AND DISCUSSION

3.1. Modeling Analysis

Results of modeling that have convergent and validated are then used for the analysis process. As a reference to simplify analysis after variations, the following table shows the turbine extraction steam flow properties and the increase in water temperature for each closed feed water heater.

Table 6. Steam extractions properties inlet heater

| Heater  | Ext. Steam Flow (kg/s) | Temperatur (deg C) | Tekanan (bar) | Entalpi (kJ/kg) | Kenaikan Temperatur (deg C) |
|---------|------------------------|--------------------|---------------|-----------------|-----------------------------|
| LPH A   | 6.19                   | 101.56             | 0.3999        | 2686.74         | 30.3                        |
| LPH B   | 5.023                  | 184.93             | 1.258         | 2844.34         | 28                           |
| LPH C   | 5.262                  | 254.59             | 2.975         | 2977.34         | 30                           |
| Deaerator | 6.865                | 316                | 6.01          | 3095.31         | 27                           |
| HPH E   | 7.248                  | 420.95             | 13.7          | 3303.62         | 37                           |
| HPH F   | 9.953                  | 354                | 30.43         | 3124.52         | 41                           |
3.2. The Effect Of Off Service Closed Feedwater Heater On Power Plant Performance

The analysis is carried out by several modeling variations of the condition of the off service feed water heater toward maintained output. This was done to determine the effect of each closed feed water heater on the performance of the power plant. PLTU performance is expressed in terms of NPHR.

Based on figure 5 above, it is seen that HPH F has the greatest influence on the increase of NPHR. When HPH F off service causes an increase of NPHR from 2574.66 kCal/kWh to 2605.24 kCal/kWh. This is due to the increased amount of needed heat in the heating process in the boiler to produce steam.

The absence of further heating process of the feedwater after exiting HPH E causing the temperature of the feedwater into the boiler turning lower. Seeing the highest increase in feed water temperature after passing HPH F, it can be said that HPH F has the biggest role in preheating in a series of regenerative closed feedwater heaters.

The highest increase of boiler intake heat occurred when HPH F was off service, which rose into 6376.5 kW. While the lowest increase in boiler heat occurs when LPH C is off service, which is only 2290.94 kW. Based on the two graphs above, it can be seen that the increase of NPHR due to off service feed water heater tends to be equal to the increase of heat intake boiler.

3.3. The Effect Of Off Service LPH vs HPH On Power Plant Performance
Figure 7. NPHR graph against variations of off service LPH and HPH

Figure 7 shows the increase of NPHR in the condition of all LPH or HPH not operating. An increase of NPHR when the condition of all HPHs off service was 69.71 kCal/kWh. Whereas the increase in NPHR in all off service LPH conditions was 57.57 kCal/kWh. So it can be seen that the effect of off service of all HPH is more significant to the increase in NPHR compared to the decrease in NPHR due to off service of all LPHs. The increase of NPHR is caused by the increase of the amount of energy needed by the power plant to produce electricity in the same amount.

Figure 8. Graph of heat input to boiler against variations of off service LPH dan HPH

The increase of the amount of needed heat in the condition of all HPH off-service concessions increased by 14188.53 kW. Whereas in the condition of all LPH off services, the increase in the amount of heat needed only increased by 11226.28 kW when compared to the condition of all feedwater heaters operating. The increased heat requirement is due to the low temperature of the feedwater entering the boiler.

3.4. The Effect Of Off Service HPH On Power Plant Performance

Based on discussion above, HPHs that are not operating have a significant reduction impact on power plant performance comparing to inactive LPHs. In actual conditions, it is also believe the most often type of closed feedwater heater showing damage or leakage is HPH, in this case HPH E and HPH F. Thus, further analysis of the effect of off-service HPH on power plant performance is carried out.

Table 7. Performance of power plants on variations of off service HPH

| Parameter       | Unit       | LPH & HPH Operasi | Off Service HPH | HPH E | HPH F | HPH E & F |
|-----------------|------------|-------------------|----------------|-------|-------|-----------|
| Efficiency      | %          | 33.396            | 33.121         | 33.004| 32.516|           |
| NPHR            | kCal/kWh   | 2574.659          | 2596.06        | 2605.24| 2644.37|           |
| W Net           | kW         | 168812.6          | 168806         | 168935.6| 168975.7|           |
| Q boiler        | kW         | 505477.1          | 509658         | 511854| 519666|           |
| Tin boiler      | deg C      | 235.05            | 226.85         | 192.23| 160.75|           |

Based on table 7, the lowest efficiency occurs when the two HPH do not operate, which is only 32.516%. This happens because the amount of energy needed to heat the feedwater into superheated steam in the boiler increases the most. The increase in heat entering the boiler is caused by the low temperature of the feed water before entering the boiler due to the absence of further heating after the feedwater exits from deaerator.
If it is only compared between HPH E and HPH F. Then HPH F has a more significant effect on the decline in power plant performance. This is because the increase in boiler heat when HPH F is not operating is greater than when HPH E is not operating. The heat entering the boiler when HPH F off service increased by 6376.9 kW. Whereas when HPH E was off service, the heat entering the boiler only increased by 4180.9 kW when compared to the condition of the entire feedwater heater operating.

The lower the temperature of feedwater entering the boiler, the higher the heat energy needed in the boiler.

3.5. The Effect Of Number Operated Feedwater Heater On Power Plant Performance

Figure 10 above shows the relationship between the number of operated closed feedwater heaters and the power plant performance expressed in thermal efficiency. It is seen that efficiency continues to increase with the increasing number of closed feedwater heaters in operation. There is no optimum point on the graph. This can be concluded that the use of 5 closed feedwater heaters in the plant with a 172 MW load capacity can be consider efficient. The best efficiency is achieved when all closed feedwater heaters operate at 33.397%.

The more closed feedwater heaters kept operate, the better preheat feedwater and the temperature of feedwater flowing into the boiler is higher. The higher the temperature of the feedwater flowing into the boiler on the same pressure, the smaller the amount of heat will be needed to convert the feedwater into superheated steam. This is seen in the table 9. The smaller amount of needed heat to generate the same output generator, the better efficiency obtained.
4. CONCLUSIONS

Based on the results of data analysis and discussion, the following conclusions are obtained. Off service feedwater heater causes an increase in NPHR. The highest increase in NPHR occurred when HPH F was not operating, reaching 30.58 kCal/kWh compared to the condition of all feedwater heaters operating. The increase in NPHR was due to the increased need for boiler heat by 6376.5 kW.

Increase of NPHR on all off service HPH by 6376.9 kW, while the HPH E off service heat increase of boiler heat when HPH F is not operating greater than when HPH E is not operating. The heat by 14188.9 kW with a NPHR of 2644.37 kCal/kWh. The increase in NPHR was due to the increased need for boiler heat by 6376.5 kW.

In the off-service HPH variation, the worst efficiency occurs when the two HPH are not operating, with a NPHR of 2644.37 kCal/kWh. The increase in NPHR was due to the increased need for boiler heat by 14188.9 kW.

HPH F has a more significant effect on the decrease in performance of PLTU. This is caused by an increase of boiler heat when HPH F is not operating greater than when HPH E is not operating. The heat input boiler when HPH F off service increased by 6376.9 kW, while the HPH E off service heat input boiler only increased by 4180.9 kW when compared to the condition of all feedwater heaters operating.

The more number of operated feedwater heater increase, the more efficiency it does.

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Table 8. Power plant performance in each simulation variation

| Variasi | LPH A | LPH B | LPH C | HPH E | HPH F | NPHR (kCal/kWh) | Eff (%) | Wnet (kW) | Qin (kW) |
|---------|-------|-------|-------|-------|-------|----------------|---------|----------|---------|
| 1       | OFF   | OFF   | OFF   | OFF   | OFF   | 2700.99        | 31.835  | 168922.7 | 536026.38 |
| 2       | OFF   | OFF   | OFF   | OFF   | OFF   | 2667.44        | 32.235  | 168958.9 | 524147.44 |
| 3       | OFF   | OFF   | OFF   | OFF   | OFF   | 2651.54        | 32.428  | 168973.3 | 521067.16 |
| 4       | OFF   | OFF   | OFF   | OFF   | OFF   | 2644.37        | 32.516  | 168975.7 | 519666  |
| 5       | OFF   | OFF   | OFF   | OFF   | OFF   | 2605.24        | 33.005  | 168935.6 | 511853.97 |
| 6       | OFF   | OFF   | OFF   | OFF   | OFF   | 2574.66        | 33.397  | 168812.6 | 505477.47 |

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