PROCEEDING

FIRST ANNUAL
UNIVERSITAS MALAHAYATI
ON GREEN TECHNOLOGY AND
ENGINEERING

On July 25 – 26th, 2007

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UNIVERSITAS MALAHAYATI
BANDAR LAMPUNG
2007
FOREWORD

The International Seminar on Green Technology and Engineering 2007 (ISGTE 2007) Faculty of Engineering, Universitas Malahayati was conducted on 25–26 July 2007. The Seminar was organized by Faculty of Engineering and collaborated with International Islamic University Malaysia (IIUM) and University Putra Malaysia (UPM).

The participants of the seminar are about 200 participants come from more than 20 higher institutions, among others: Unhas, ITS, UI, Tri Sakti, ITB, Unila, Unisri, Unibraw, UPM (University Putra Malaysia), IIUM (International Islamic University Malaysia), UTM University Technology Malaysia), and others, which reflect the importance of Green Technology and Engineering. The concept of sustainable development based on the environmental firmament nowadays has become central issues in many development as well as developed countries. These issues are very important and the topic of this issue can create awareness of the societies to involve in the development of their country toward the sustainable development.

The seminar provide platform for researchers, engineers and academician to meet and share ideas, achievement as well as experiences through the presentation of papers and discussion. These events are important to promote and encourage the application of new techniques to practitioners as well as enhancing the knowledge of engineers with the current requirements of analysis, design and construction of any engineering concept. Seminar also functions as platform to recommend any appropriate remedial action for the implementation and enforcement of policies related to environmental engineering fields. Furthermore, this seminar provides opportunities to market faculties’ expertise in the field environmental engineering, civil engineering, structural engineering, mechanical engineering and so on.

On behalf of Steering Committee, we would like to express our deepest gratitude to the Foundation Alih Technology, Rector Universitas Malahayati, International Advisory Board members, and also to all participants. We are also grateful to all organizing committee and all the reviewers, without whose efforts such a high standard for the seminar could not have been attained. We would like to express our deepest gratitude to the Faculty of Engineering Universitas Malahayati for conducted such seminar. This is the first International Seminar for the Faculty and we expect that this is will become annual activity for the Faculty of Engineering.

Bandar Lampung, 25 July 2007

Agung Efriyo Hadi
The Organizing Chairman
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UNIVERSITAS MALAHAYATI
INTERNATIONAL SEMINAR
ON GREEN TECHNOLOGY AND ENGINEERING

On July 25 – 26th, 2007

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SIMULATION OF THERMAL EFFICIENCY OF STEAM POWER PLANT BUKIT ASAM BY USING NEWTON RAPHSON METHOD

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Abstract

This research intents on increase of thermal efficiency of Steam Power Plant Bukit Asam. Method used is by making simulation in use of Newton Raphson Method. The steps are, first make function of mathematical equations of test performance data up to three periods in one year and energy balance equations, second solve mathematical function equations by making simulation program in use of Newton Raphson Method.

After simulation has been performed, it is acquired that thermal efficiency increases 4% and electricity production increases by 3.26 MW.

Keywords: Simulation, thermal efficiency, power plant.

1. INTRODUCTION

Based on data specification of four units (unit 1 to 4) of steam turbine power plants, the assembled electrical power produced by each unit is 65 MW/unit. But according to the field survey of steam turbine power plant unit 4, the performance test result in one year for three periods on January, June and December, shows that electricity production yielded always changes that tends to decrease between 5 to 15% of assembled power [3].

Besides electricity decreasing trend can also be seen from daily electricity production data in a year. There are some factors that influence electricity production decreases, one of them is caused by operation variables of generator system (i.e. in boiler, turbine, generator, condensor, and heater) that always change so they influence the rate of energy system accumulatively that will impact in thermal efficiency and in turn ascendant in unstable electricity production. One of impact which may happen because of unstability of electricity production is lack of electricity supply that causes rotated extinction especially in peak loads [4].

To solve this problem, there are some ways can be done, e.g. replacing old to new power plant or maintaining the existing power plant. Maintenance can be meant as a coherent activity between administration and finance to keep and or bringing back asset condition (steam power plant units) so it can reach the aim expected. One of them is having high thermal efficiency and production of electricity [5].

In relation to this, therefore thermal efficiency needs to be improved, increasing thermal efficiency will finally increase electricity production. Benefit from simulation in this research is we can modify operation variables within designed capacity limits (design condition), arrange operational condition correction or calibration to arrange improvement in more economical cost, and give opinion contribution in order to increase thermal efficiency and electricity production.
2. LITERATURE REVIEW

Based on theoretical study result, it is stated that change of electricity production of steam power plant are caused by some factors, amongst those are fuel consumption and operational variable of main component of the steam power plant. Refer to performance test result, it is known that the mass flow rate of fuel in 3 periods is relatively stable for 0, 44 kg/kWh but operational conditions of main components such as temperature, pressure, enthalpy, and mass flow rate are always arbitrary. The changing of these parameters will impact in changing thermal efficiency that in turn will impact the electricity production becomes unstable.

There are many methods to make simulation; some of them are Bisection, Iteration, Gauss-Seidel, Jacobi, and Newton Raphson method [15]. In order to get better final result from the methods above, we can use Newton Raphson Method [7]. The excellence of Newton Raphson method besides we can get more accurate prediction, it can be used for functions that have either linear or nonlinear variables.

The performance of a turbo machine can be described by using graph, the relationship among variables in that machine e.g. flow rate (Q), speed variation (n) and pressure change (ΔP) will in general give results in mathematical equations [11].

Simulation system is a calculation of operational variables (i.e. pressure, temperature, mass flow rate, etc.) in thermal system for steady state condition. Equations of performance characteristics of components and thermodynamic characteristics of mass and energy balance form a group of simultaneous equations of operational variables, thus simulation of thermal system solves the linear or non linear equations.

Thermal system of a steam power plant is a repetitive cycle system, that its energy flow can be analyzed by first law of thermodynamic for energy flow which penetrates in a system as mass and volume control [13]. Application of the first law of thermodynamic for volume control is shown in Figure 1.

![Figure 1: Energy Flow Penetrates Volume Control](image_url)

By assuming process is occurred in a steady state condition therefore energy balance for volume control can be written as in equation (1). This equation can be applied to analyze boiler, turbine, condenser, pump, feed water heater, etc.

\[ W_{\text{process}} + Q \sum_{m} m \times h = \sum_{out} m \times h \quad \text{(1)} \]

Generally working fluid used in steam power plant is water (H₂O). Rankine cycle is a standard cycle for steam power plant by using liquid-vapor phase [12] which are shown in Figure 2 and 3 below.
Figure 2: Ideal Rankine cycle

Where:
\[ Q_A : \text{Heat enter to steam generator (SG)} \]
\[ Q_R : \text{Heat rejected from condensor (C)} \]
\[ W_P : \text{Work of pump (P)} \]

Figure 2 shows that superheat steam (1) resulted by steam generator (SG) then enter turbine (T) and results turbine work \( W_T \). Steam resulted from turbine expansion (2) goes to condensor (C) as saturated liquid (3), this saturated liquid is pumped by pump (P) to steam generator (SG) to be evaporated and then return to (1).

Figure 3: T-S diagram for ideal Rankine cycle

Figure 3 shows that cycle 1 - 2 - 3 - 4 - 1 is superheat Rankine cycle. The process occurred is as follows:

1 - 2 = Expansion of reversible adiabatic process occurs, commonly the fluid comes from turbine is in two phases.

2 - 3 = Constant temperature in two phases, heat is rejected out from condensor with constant pressure.

3 - 4 = Pumping process of reversible adiabatic, saturated liquid from condensor is pumped and the pressure is increased from \( P_3 \) to \( P_4 \).

4 - 1 = Process of heat added into steam generator.
3. METHODOLOGY

The simulation program of thermal efficiency can be described as follows:

1. The diagram of energy flow of steam power plant Bukit Asam is drawn and analyzed by the use of Rankine cycle.

![Figure 4: Cycle diagram of steam power plant Bukit Asam](image)

Data available in Figure 4 are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>87</td>
<td>bar</td>
</tr>
<tr>
<td>$P_4$</td>
<td>0.4</td>
<td>bar</td>
</tr>
<tr>
<td>$P_2$</td>
<td>3</td>
<td>bar</td>
</tr>
<tr>
<td>$T_1$</td>
<td>510</td>
<td>°C</td>
</tr>
<tr>
<td>$m_2$</td>
<td>4300 kg/s</td>
<td></td>
</tr>
<tr>
<td>$P_3$</td>
<td>0.8</td>
<td>bar</td>
</tr>
<tr>
<td>$\eta_G$</td>
<td>98%</td>
<td></td>
</tr>
</tbody>
</table>

Parameters that will be calculated are:

**Pump**

Efficiency of Pump:

$$\eta_p = \frac{m(h_6 - h_5)}{W_p} \quad \text{...... (2)}$$

where:

- $\eta_p$ = Efficiency of pump
- $W_p$ = Worked done by pump
- $m$ = Mass flow rate
- $h_5$ = Entalphy of condensor
- $h_6$ = Entalphy of pump

![Figure 5: Energy Balance of Pump](image)
Boiler

Its mathematical equation is:
\[ q_A = m_1(h_i - h_b) + q_g \] ..... (3)

Efficiency of Boiler:
\[ \eta_B = \frac{m_1(h_i - h_b)}{q_A} \] ..... (4)

where:
- \( q_g \) = Heat rejected from boiler
- \( q_A \) = Heat input to boiler
- \( h_i \) = Entalphy of boiler
- \( h_b \) = Entalphy of FWH

Figure 6: Energy Balance of Boiler

Turbine

Its energy balance equation is:
\[ m_1 = m_2 + m_3 + m_4 \] ..... (5)

\[ W_r = \eta_G \cdot \eta_t (m_1h_1 - m_2h_2 - m_3h_3 - m_4h_4) \] ..... (6)

Figure 7: Energy Balance of Steam Turbine

Condensor

Its energy balance equation is:
\[ (m_2 + m_3)h_{10} + m_4h_4 = m_2h_2 + m_3h_3 + mC_p\Delta T \] ..... (7)

Where:
- \( m_2, m_3, m_4, m_5 \) = Mass flowrate
- \( m \) = Mass flowrate of cooling water (4300 kg/s)
- \( C_p \) = Specific heat of cooling water (4.19 kJ/kgK)
- \( q_c \) = Heat absorbed by cooling water (Heat is discarded to environment)

Figure 8: Energy Balance of Condensor

FWH 1

Its energy balance equation is:
\[ m_1(h_f - h_b) + (m_2 + m_3)h_{10} = m_2h_0 + m_3h_3 \] ..... (8)

Figure 9: Energy Balance of FWH 1
Its energy balance equation is:

\[ m_1 (h_8 - h_7) = m_2 (h_2 - h_9) \]  

(9)

Figure 10: Energy Balance of FWH 2

3. The Mathematical Equations Of Performance Test Graph On January, June And December And Energy Balance Are Set Up.


FLOW CHART OF SIMULATION PROGRAM
5. Run the simulation program.
6. Thermal efficiency of each period is determined.
7. From the results: 18 variables those are looked for can be determined as:
\[ W_T, q_A, q_B, q_c, m_1, m_2, m_3; m_4, \eta_k, \eta_p; h_6; h_7; h_8; h_9; h_{10}; T_6; T_7; T_8 \]
8. Determine thermal efficiency by use of equation,
\[ \eta_{th} = \frac{W_T - W_P}{q_A} \times 100% \]
9. Compare thermal efficiency and electricity production yielded before and after simulation for each period.

4. RESULTS AND DISCUSSION

Based on performance test data for three periods on January, June and December and energy balance in steam power plant Bukit Asam cycle, the mathematical function equations that can be obtained as follows:

<table>
<thead>
<tr>
<th>Table 1: Mathematical function of equations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>January 2003</strong></td>
</tr>
<tr>
<td>[ T_8 = -0.14 W_T^2 + 18.3 W_T - 406 ]</td>
</tr>
<tr>
<td>[ \eta_p = 0.008 m_1^2 - 4.0499 m_1 + 582.52 ]</td>
</tr>
<tr>
<td>[ m_1 = -0.0197 q_A^2 + 22.604 q_A - 620.1 ]</td>
</tr>
<tr>
<td>[ T_7 = -0.1136 W_T^2 + 13.932 W_T - 8.29 ]</td>
</tr>
<tr>
<td>[ \eta_B = 0.005 W_T^2 - 0.637 W_T + 111.8 ]</td>
</tr>
<tr>
<td>[ W_T = 0.0037 q_A^2 + 4.3563 q_A - 202.6 ]</td>
</tr>
<tr>
<td>[ T_8 = -0.722 W_T^2 + 90.97 W_T - 2466.3 ]</td>
</tr>
<tr>
<td>[ T_8 - T_7 = -2.2651 m_2^2 + 832.35 m_2 - 76356 ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: Mathematical Function Equations of Energy Balance of Steam Power Plant Bukit Asam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematical Equation of Balance of Energy (January, June and December) 2003</td>
</tr>
<tr>
<td>1. [ \eta_p = \frac{m(h_6 - h_5)}{W_P} ]</td>
</tr>
<tr>
<td>2. [ q_A = m_1(h_1 - h_8) + q_s ]</td>
</tr>
</tbody>
</table>
3. \[ \eta_B = \frac{m_1(h_1 - h_{5})}{q_A} \]
4. \[ m_1 = m_2 + m_3 + m_4 \]
5. \[ W_T = \eta_o \cdot \eta_T (m_1 h_1 - m_2 h_2 - m_3 h_3 - m_4 h_4) \]
6. \[ (m_2 + m_3)h_0 + m_4 h_4 = m_2 h_5 + m_4 h_5 \]
7. \[ m_1(h_5 - h_6) + (m_2 + m_3)h_0 = m_2 h_5 + m_4 h_5 \]
8. \[ m_1(h_6 - h_1) = m_2(h_2 - h_6) \]
9. \[ h_8 - h_7 = m_1C_p \Delta t \]
10. \[ q_A = q_g + q_c + \frac{W_T}{\eta_o \eta_T} \]

After program runs, the operational variables for January, June and December 2003 are obtained (see Table 3) as follows:

**Table 3: Results of Simulation Program, Operational Variables of Steam Power Plant**

<table>
<thead>
<tr>
<th>Variable Code</th>
<th>Variable</th>
<th>Year 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>January</td>
</tr>
<tr>
<td>X_1</td>
<td>W_T (MW)</td>
<td>58,594</td>
</tr>
<tr>
<td>X_2</td>
<td>q_A (MW)</td>
<td>327,589</td>
</tr>
<tr>
<td>X_3</td>
<td>q_g (MW)</td>
<td>22,668</td>
</tr>
<tr>
<td>X_4</td>
<td>\eta_B (%)</td>
<td>0,828</td>
</tr>
<tr>
<td>X_5</td>
<td>\eta_p (%)</td>
<td>0,796</td>
</tr>
<tr>
<td>X_6</td>
<td>T_g (°C)</td>
<td>174,900</td>
</tr>
<tr>
<td>X_7</td>
<td>T_1 (°C)</td>
<td>212,223</td>
</tr>
<tr>
<td>X_8</td>
<td>T_8 (°C)</td>
<td>341,021</td>
</tr>
<tr>
<td>X_9</td>
<td>h_6 (MJ/kg)</td>
<td>2,877</td>
</tr>
<tr>
<td>X_10</td>
<td>h_7 (MJ/kg)</td>
<td>4,667</td>
</tr>
<tr>
<td>X_11</td>
<td>h_8 (MJ/kg)</td>
<td>0,805</td>
</tr>
<tr>
<td>X_12</td>
<td>h_9 (MJ/kg)</td>
<td>1,109</td>
</tr>
<tr>
<td>X_13</td>
<td>h_10 (MJ/kg)</td>
<td>2,202</td>
</tr>
<tr>
<td>X_14</td>
<td>m_1 (kg/s)</td>
<td>86,832</td>
</tr>
<tr>
<td>X_15</td>
<td>m_2 (kg/s)</td>
<td>169,607</td>
</tr>
<tr>
<td>X_16</td>
<td>m_3 (kg/s)</td>
<td>140,507</td>
</tr>
<tr>
<td>X_17</td>
<td>m_4 (kg/s)</td>
<td>194,174</td>
</tr>
<tr>
<td>X_18</td>
<td>q_c (MW)</td>
<td>123,126</td>
</tr>
</tbody>
</table>

Based on the simulation results, comparison among each variable in each period is as indicated on Table 4 below:
Table 4: Comparison of Operational Variable before and after Simulation

<table>
<thead>
<tr>
<th>Variable Code</th>
<th>January</th>
<th>June</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New</td>
<td>Old</td>
<td>New</td>
</tr>
<tr>
<td>$W_T$ (MW)</td>
<td>58,594</td>
<td>57,1</td>
<td>61,018</td>
</tr>
<tr>
<td>$q_A$ (MW)</td>
<td>175,893</td>
<td>296,33</td>
<td>166,359</td>
</tr>
<tr>
<td>$q_g$ (MW)</td>
<td>22,668</td>
<td>21,347</td>
<td>146,653</td>
</tr>
<tr>
<td>$\eta_B$ (%)</td>
<td>0,828</td>
<td>0,915</td>
<td>0,892</td>
</tr>
<tr>
<td>$\eta_p$ (%)</td>
<td>0,796</td>
<td>0,704</td>
<td>0,863</td>
</tr>
<tr>
<td>$T_g$ (°C)</td>
<td>174,900</td>
<td>185,66</td>
<td>175,687</td>
</tr>
<tr>
<td>$T_7$ (°C)</td>
<td>212,222</td>
<td>380,66</td>
<td>188,204</td>
</tr>
<tr>
<td>$T_8$ (°C)</td>
<td>341,021</td>
<td>362,33</td>
<td>239,605</td>
</tr>
<tr>
<td>$h_6$ (MJ/kg)</td>
<td>2,877</td>
<td>2,384</td>
<td>2,780</td>
</tr>
<tr>
<td>$h_7$ (MJ/kg)</td>
<td>4,667</td>
<td>36,04</td>
<td>4,366</td>
</tr>
<tr>
<td>$h_8$ (MJ/kg)</td>
<td>0,805</td>
<td>0,90761</td>
<td>0,909</td>
</tr>
<tr>
<td>$h_9$ (MJ/kg)</td>
<td>1,109</td>
<td>1,201</td>
<td>0,989</td>
</tr>
<tr>
<td>$h_{10}$ (MJ/kg)</td>
<td>2,202</td>
<td>2,320</td>
<td>1,705</td>
</tr>
<tr>
<td>$m_1$ (kg/s)</td>
<td>86,832</td>
<td>85,163</td>
<td>85,476</td>
</tr>
<tr>
<td>$m_2$ (kg/s)</td>
<td>169,607</td>
<td>185,4</td>
<td>180,550</td>
</tr>
<tr>
<td>$m_3$ (kg/s)</td>
<td>140,507</td>
<td>141,563</td>
<td>123,364</td>
</tr>
<tr>
<td>$m_4$ (kg/s)</td>
<td>194,174</td>
<td>231,43</td>
<td>197,027</td>
</tr>
<tr>
<td>$q_e$ (MW)</td>
<td>123,126</td>
<td>143,502</td>
<td>160,818</td>
</tr>
</tbody>
</table>

From the results above, accumulatively one variable component will regard the other ones that eventually will impact in thermal efficiency of power plant. Thermal efficiency can be calculated by using equation

$$\eta_{th} = \frac{W_T - W_P}{q_A}$$

By assuming,

$$W_T = X_1$$

$$q_A = X_2$$

The thermal efficiency before and after simulation is obtained as shown in Table 5.
Table 5: Comparison of thermal efficiency before and after simulation

<table>
<thead>
<tr>
<th>Variable Code</th>
<th>January</th>
<th>June</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New</td>
<td>Old</td>
<td>New</td>
</tr>
<tr>
<td>(X_1)</td>
<td>58,594</td>
<td>57,1</td>
<td>61,018</td>
</tr>
<tr>
<td>(X_2)</td>
<td>327,589</td>
<td>269,33</td>
<td>404,586</td>
</tr>
<tr>
<td>(X_3)</td>
<td>0,796</td>
<td>0,7034</td>
<td>0,863</td>
</tr>
<tr>
<td>(X_4)</td>
<td>2,877</td>
<td>2,384</td>
<td>2,780</td>
</tr>
<tr>
<td>(X_{14})</td>
<td>86,832</td>
<td>85,163</td>
<td>78,475</td>
</tr>
<tr>
<td>(\eta_{th}(%))</td>
<td>17,666</td>
<td>16,512</td>
<td>15,070</td>
</tr>
</tbody>
</table>

From the results above, it is acquired that the most profitable thermal efficiency increase is in December 2003 for 4% with electricity production increase to 3,26 MW.

5. CONCLUSION

This research has been conducted by simulation of thermal efficiency of steam power plant Bukit Asam. The method used in solving mathematical function equations of test performance data up to three periods in one year and energy balance equations. After simulation has been performed, it is acquired that thermal efficiency increases 4% and electricity production increases by 3,26 MW.

REFERENCES

