Vol. 1 No. 2 page 52-56 2015
DOI:10.14456/randk.2015.10

RESEARCH & KNOWLEDGE

Research Article

Power plant efficiency improvement by optimizing main influential control parameters

Polachate Tosomboon and Thosapon Katejanekarn*

Building Energy Systems Laboratory, Department of Mechanical Engineering,
Faculty of Engineering and Industrial Technology, Silpakorn University,
Nakhon Pathom 73000, Thailand.

(Received 19 November 2015; accepted 25 December 2015)

Abstract - This study was an attempt to increase power plant efficiency by adjusting the process control parameters that resulted from a numerical analysis of the power plant efficiency and its relevant operating parameters. The optimum values for the four main control parameters that would make the power plant run at the maximum efficiency were evaluated for two regular load levels of 245 and 300 MW. The optimum values from the model were validated against the plant simulator due to the fact that it was too risky to adjust the real power plant. The results showed that if the plant was operated at the optimum combinations of the main control parameters, the efficiency of the plant at the load levels of 245 and 300 MW would be 0.3859 and 0.3935, respectively. From the operating data during the last two years, the plant efficiency at these two load levels would be improved by 0.0178 and 0.0149, which is equivalent to natural gas cost savings of 752,704 Baht/day (about 22,138 US$/day) and 609,862 Baht/day (about 17,937 US$/day), respectively.

Keywords: Power plant efficiency, optimization, control parameters, numerical analysis

1. Introduction

In Thailand, electrical energy consumption has increased by approximately 4.3% annually (Energy Policy and Planning Office, 2014), which in turn causes the country to build more power plants to meet the demand. More than 80% of energy sources to produce electricity in Thailand are fossil fuels. Natural gas (NG) shares 67% of the energy mix (Electricity Generating Authority of Thailand, 2015a), of which around 60% comes from the gulf of Thailand and around 40% has to be imported (Electricity Generating Authority of Thailand, 2015b).

Electrical power plants are one of the most intense fossil fuel consumers. With a slight improvement in their efficiency, a significant amount of savings can be obtained. For example, a 735-MW power plant fueled by natural gas currently operates at an efficiency of 35.12%. If the efficiency is improved by only 1%, the fuel cost would be reduced by as much as 542,450 Baht per day or 198 million Baht (about 5.8 million US$) per year (based on the cost of natural gas of 300 Baht or 8.8 US$ per MMBtu).

There are several methods to improve the efficiency of power plants. Some methods require a high investment to improve, replace, or install equipment, for example, upgrading the boiler and installing an air separation unit resulting in a 3.3-4.0% higher efficiency (Kotowicz and Balicki, 2014), installing a low-pressure economizer resulting in a 0.46% higher efficiency (Wang *et al*., 2014), and changing the angles of the chimney walls and slopes of the collectors resulting in a 0.53% higher efficiency (Ghorbani *et al*., 2015).

Adjusting the process control parameters is another group of methods that can improve efficiency with much less, or even no, investment, for example, increasing the steam inlet temperature from 508 to 568^{o}C and keeping the pressure constant at 124.61 bar can cause a 3.79% higher efficiency (Geete and Khandwawala, 2013), tuning the pre-dried lignite-fired power system causes a 1.51% higher efficiency (Han *et al*., 2014), and modifying the combustion control systems causes a 1.69% higher efficiency (Mikulandric *et al*., 2013).

Power plant efficiency analysis may be performed in two ways. One is performing a theoretical thermodynamic analysis, which is accurate but could be quite complicated. The other is analyzing it numerically, which is more rapid and simple but less accurate.

In this study, a thermal power plant was analyzed numerically to improve its efficiency by adjusting the process control parameters. Four main influential control parameters were optimized to achieve combinations that yield the highest efficiency at two regular operating loads of 245 MW and 300 MW. The results were then validated against the plant simulator, due to the risk involved with an actual test with the real plant.

*Author for correspondence: thosaponk@hotmail.com

2. Methodology

A 735-MW thermal power plant was studied in this work. It is operated 24 hours a day and fueled mainly by natural gas. The secondary fuel is heavy oil. There are 12 main control parameters, as shown in Table 1. By considering which ones influence the efficiency the most and can be adjusted by the operators in the control room, four control parameters (reheat steam temperature, condenser vacuum, final feed water temperature, and excess oxygen) were selected as the most influential ones that would be optimized in this study.

Table 1. Main control parameters of power plant.

Item	Description	Unit
1	Main steam pressure	bar
2	Main steam temperature	°C
3	Reheat steam pressure	bar
4	Reheat steam temperature	°C
5	Final feed water temperature	°C
6	Feed water flow	t/h
7	Superheat spray water flow rate	t/h
8	Reheat spray water flow rate	t/h
9	Condenser vacuum	bar
10	Stack temperature	°C
11	Excess oxygen	%
12	Circulating water temperature	°C

A multiple least-squares regression model was formed to evaluate the power plant efficiency in terms of the four main influential control parameters, as shown in Eq. (1).

$$\begin{aligned}\eta = \; & a_0 + a_1A + a_2A^2 + a_3A^3 + a_4A^4 + \ldots \\ & + a_5B + a_6B^2 + a_7B^3 + a_8B^4 + \ldots \\ & + a_9C + a_{10}C^2 + a_{11}C^3 + a_{12}C^4 + \ldots \\ & + a_{13}D + a_{14}D^2 + a_{15}D^3 + a_{16}D^4 + \ldots \end{aligned} \quad (1)$$

where, η = power plant efficiency,

A, B, C, D, … = main influential control parameters,

$a_0, a_1, a_2, a_3, \ldots$ = coefficients.

By applying a statistical analysis to the operating data of the power plant from the last two years, only the terms that have significant effects were maintained in the model.

To find the optimum values of the four main parameters that give the highest plant efficiency, the concept of univariate search was implemented. The first parameter was varied while the remaining three parameters were kept constant until the maximum efficiency was reached, then the value of the first parameter was fixed at this point. After that, the next parameter was varied while the other three were fixed until the maximum efficiency was achieved. This process was repeated until the values of all four parameters did not change anymore. Then, the final values of the four parameters were considered to be the optimum values.

The search for the optimum values of the four main parameters was carried out at two regular load levels of the power plant, which were 245 and 300 MW. The results from the regression model were then compared with the results from the plant simulator, due to the fact that it was too risky to perform a test with the real plant. If the difference between the results from the regression model and the plant simulator did not exceed the propagated error of the plant efficiency, the optimum values of the four parameters were considered to be valid.

3. Results and Discussion

3.1 Reliability of plant simulator

Since it was not possible to adjust the main four control parameters in the real power plant, the plant simulator was used instead. Table 2 shows the comparison between the operating parameters retrieved from the real power plant and the ones obtained from the plant simulator at the regular load level of 245 MW. It can be seen that the real values and the values from the plant simulator were very close to each other. The highest difference was 1.73%, which was smaller than the average uncertainty (2%) of the measuring devices in the power plant. The comparisons were done on many sets of operating data and the findings were always similar. Therefore, it can be concluded that the plant simulator is reliable and can represent the real power plant.

3.2 Power plant efficiency models

Starting from the full form of the model according to Eq. (1) and then applying a statistical analysis, only the terms that have significant effects were kept. The power plant efficiency models for the regular load levels of 245 and 300 MW were obtained as shown in Eqs. (2) and (3), respectively.

Table 2. Comparison between main control parameters from actual data and plant simulator (sample data set at load level of 245 MW).

Item	Description	Unit	Actual data	Simulator data	Difference (%)
1	Electrical power load	MW	245.10	245.00	0.04
2	Main steam pressure	bar	116.38	116.33	0.04
3	Main steam temperature	°C	508.17	508.00	0.03
4	Reheat steam pressure	bar	15.85	15.77	0.51
5	Reheat steam temperature	°C	505.49	504.90	0.12
6	Final feed water temperature	°C	227.41	227.00	0.18
7	Feed water flow rate	t/h	787.32	779.00	1.06
8	Superheat spray water flow rate	t/h	19.66	20.00	-1.73
9	Reheat spray water flow rate	t/h	0.00	0.00	0.00
10	Condenser vacuum	bar	0.4666	0.4669	0.07
11	Stack temperature	°C	80.69	81.54	-1.05
12	Excess oxygen	%	5.83	5.89	-1.03
13	Circulating water temperature	°C	26.29	26.36	-0.27

$$\eta = 0.0275X_R + 125.1040X_C^2 - 13.6364X_C - 0.0009X_F^2 + 0.0115X_O^3 - 1.1744X_O + 76.2771 \quad (2)$$

$$\eta = -0.0323X_R + 0.3420X_C^2 + 0.2220X_C + 0.0023X_F^2 + 1.7405X_O^2 + 2.0392X_O + 38.1421 \quad (3)$$

where, X_R = reheat steam temperature (°C),
X_C = condenser vacuum (bar),
X_F = final feed water temperature (°C),
X_O = excess oxygen (%).

3.3 Optimum values of main control parameters

The optimum values of the four main influential control parameters at the regular load level of 245 MW obtained from the univariate search concept are shown in Table 3. The power plant efficiency as calculated from the model shown in Eq. (2) was 0.3859, while the efficiency from the plant simulator was 0.3867. The difference between the two values was 0.0008, which was less than the propagated uncertainty of the power plant efficiency (absolute uncertainty = 0.0011, relative uncertainty = 0.33%). Therefore, this suggests that the optimum values of the main control parameters obtained from the model were valid.

The average value of the plant efficiency at the load level of 245 MW during the last two years was approximately 0.3689. If the plant could operate at the optimum efficiency obtained from the model, then the plant efficiency could be increased by 0.0178, which is equivalent to a reduced heat rate of 450.20 kJ/kWh or a natural gas cost saving of 752,704 Baht/day (about 22,138 US$/day).

Table 3. Optimum values of main control parameters at 245 MW load level.

Item	Description	Unit	Optimum Values
1	Reheat steam temperature	°C	508.22
2	Condenser vacuum	bar	0.0246
3	Final feed water temperature	°C	225.85
4	Excess oxygen	%	4.66
5	Average efficiency during the last 2 years	-	0.3689
6	Optimum efficiency from the model	-	0.3867
7	Difference	-	0.0178
8	Absolute error	-	0.0012
9	Relative error	%	0.36

The optimum values of the four main influential control parameters at the regular load level of 300 MW obtained from the univariate search concept are shown in Table 4. The power plant efficiency calculated from the model shown in Eq. (3) was 0.3935, while the efficiency from the plant simulator was 0.3910. The difference between the two values was 0.0025, which was higher than the propagated uncertainty of the power plant efficiency (absolute uncertainty = 0.0011, relative uncertainty = 0.33%). Even though more data were needed to make the optimum values of the main control parameters obtained from the model valid, according to the criteria stated in the previous section, it is still worth determining how much it would help to reduce the operating cost of the plant at this combination of the parameters.

The average value of the plant efficiency at the load level of 300 MW during the last two years was approximately 0.3761. If the plant could operate at the optimum efficiency obtained from the model, then the plant efficiency could be increased by 0.0149, which is equivalent to a reduced heat rate of 364.76 kJ/kWh or a natural gas cost saving of 609,862 Baht/day (about 17,937 US$/day).

Table 4. Optimum values of main control parameters at 300 MW load level.

Item	Description	Unit	Optimum Values
1	Reheat steam temperature	°C	529.58
2	Condenser vacuum	bar	0.0432
3	Final feed water temperature	°C	238.85
4	Excess oxygen	%	5.54
5	Average efficiency during 2 years	-	0.3761
6	Optimum efficiency	-	0.3910
7	Difference	-	0.0149
8	Absolute error	-	0.0011
9	Relative error	%	0.30

4. Conclusion

This study aimed to increase the power plant efficiency by adjusting the process control parameters using the results from a numerical analysis of the power plant efficiency and its relevant operating parameters. The optimum values of the four main control parameters that would make the power plant run at the maximum efficiency were evaluated for two regular load levels of 245 and 300 MW. The optimum values from the model were validated against the plant simulator due to the fact that it was too risky to adjust the real power plant. The results showed that if the plant was operated at the optimum combination of the main control parameters, the efficiency of the plant at the load levels of 245 and 300 MW would be 0.3859 and 0.3935, respectively. From the operating data during the last two years, the plant efficiency at these two load levels would be improved by 0.0178 and 0.0149, which would be equivalent to natural gas cost savings of 752,704 Baht/day (about 22,138 US$/day) and 609,862 Baht/day (about 17,937 US$/day), respectively.

Acknowledgements

The authors would like to thank the power plant in Ratchburi, Thailand for the data used in this study. The authors would also like to thank the Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University for the support to complete this work.

References

Geete, A. and Khandwawala, A. I. 2013. Thermodynamic analysis of 120 MW thermal power plant with combined effect of constant inlet pressure (124.61 Bar) and different inlet temperatures. Case Studies in Thermal Engineering 1(1), 17–25.

Ghorbani, B., Ghashami, M. and Ashjaee, M. 2015. Electricity production with low grade heat in thermal power plants by design improvement of a hybrid dry cooling tower and a solar chimney concept. Energy Conversion and Management 94, 1–11.

Han, X. Q., Liu, M., Wang, J., Yan, J., Liu, J. and Xiao, F. 2014. Simulation study on lignite-fired power system integrated with flue gas drying and waste heat recovery – performances under variable power loads coupled with off-design parameters. Energy 76, 406–418.

Kotowicz, J. and Balicki, A. 2014. Enhancing the overall efficiency of a lignite-fired oxyfuel power plant with CFB boiler and membrane-based air separation unit. Energy Conversion and Management 80, 20–31.

Mikulandrić, R., Loncar, D., Cvetinovi, D. and Spiridon, G. 2013. Improvement of existing coal fired thermal power plants performance by control systems modifications. Energy 57, 55–65.

Wang, C. J., He, B., Yan, L., Pei, X. and Chen, S. 2014. Thermodynamic analysis of a low-pressure economizer based waste heat recovery system for a coal-fired power plant. Energy 65, 80–90.

Energy Policy and Planning Office, 2014. Electrical consumption and production of Thailand. Ministry of Energy, Thailand. http://www.eppo.go.th, access on 16/04/2015.

Electricity Generating Authority of Thailand. 2015a. Fuel consumption for electrical generating. http://www.egat.co.th, access on 20/04/2015.

Electricity Generating Authority of Thailand. 2015b. Natural gas price and electricity charge. http://www.egat.co.th, access on 3/05/2015.