A New Signal Processing Approach to Find Parameters Affecting Fuel Consumption in Power Plants

Hadi Keshvari Khor, and Ali Karimpour,
ha_ke180@stu-mail.um.ac.ir, and karimpor@um.ac.ir,
Department of Electrical and Control Engineering,
Ferdowsi University of Mashhad

Keywords : Optimization, Fuel Consumption, Fuel Conservation, Signal Processing, Correlation Coefficient

Abstract : In this paper, a new signal processing approach for finding parameters affect fuel consumption in power plants is proposed. Boiler is a nonlinear, MIMO and time varying system with relatively large time delays and its efficiency changes with time. Many parameters affect boiler's efficiency in a power plant. Using historical process data of Mashhad power plant, the most probable parameters involve boiler efficiency are discussed. In this case, Studies show that air/fuel ratio and input gas pressure are the most important parameters can change efficiency. An increase in the air/fuel ratio will enhance thermal efficiency. In addition, because of incorrect air/fuel regulation table, the gas pressure affects air/fuel ratio and boiler efficiency.

1- Introduction

OPTIMIZATION of fuel consumption is interested in power industry. It is achievable by increasing thermal efficiency in power plants. Up to now, many researches have done to increase boiler-turbine efficiency. Kusiak and Song [1-3] used some data mining approaches to increase combustion efficiency. Kuprianov *et al.* [4-6] proposed a cost-based method for improving both fuel consumption and pollutant emissions of a boiler simultaneously. In this method, fuel cost is considered as "internal cost". The boiler pollutants produce some damages to the environment and human, which is considered as "external cost". "Total cost" is the sum of internal and external costs. The final goal of cost-based methods is to minimize "total cost" by determining the optimal excess air ratio. By performing some experiments while boiler is working with variable excess air ratios and collecting data, the total price for production of steam in different excess air ratios is calculated.

Finally, with interpolation (or extrapolation) from results of experiments, the optimal excess air ratio is determined. In fact, kuprianov proposes a test-code that minimizes boiler total cost by optimization of excess air ratio. Havlena and Findejs have reported application of model predictive control for control and optimization of combustion process [7]. Li *et al*. proposed a simple technique for searching optimal excess air ratio, online [8]. Nazaruddin *et al.* used neural network for modeling combustion process [9]. Booth and Roland have reported application of neural network in a multiobjective combustion optimization [10]. Kalogirou [11] reviewed applications of artificial intelligence for the modeling, control and optimization of combustion process. Dockrill and Friedrich discussed different ways for improving boiler efficiency [12].

2- Objective Function

The goal of this study is to decrease fuel consumption in Mashhad power station by increasing boiler efficiency and classify parameters in power plant that have an effect on fuel consumption. Nevertheless, for simplicity of calculations, the selected objective function is the ratio of active power to the fuel flow (power/fuel ratio). In fact, the selected objective function is a coefficient of the boiler-turbine efficiency and maximizing this objective function will enhance boiler efficiency. This objective function selection redound no need to calorific value of fuel.

3- Fuel Conservation Potential

Figure (1) shows the ratio of active power to the fuel flow in Mashhad power station, No.1, SKODA unit in a period of 6 days. As shown in figure (1), the power/fuel ratio deviates from 258 to 324. Since boiler-Turbine is a nonlinear time invariant system with relatively large time delays, we cannot judge with transient data. Therefore, it is wise to use averaged data. Figure (2) indicates 1, 10 and 60 minutes averaged data. With 1 minute averaged data, 5.5% fuel conservation is achievable, it will reduce to 2% and 1.8% with 10 and 60 minutes averaged data respectively.

There are two essential questions:

1- How much conservation in fuel is achievable?
2- Did the best boiler-turbine conditions (with the maximum efficiency) occur in this period of 6 days?

A set of data include 5 parameters namely active power, reactive power, gas flow to boiler, gas pressure and air flow are considered. All the parameters in this data set are averaged, normalized and denoised.

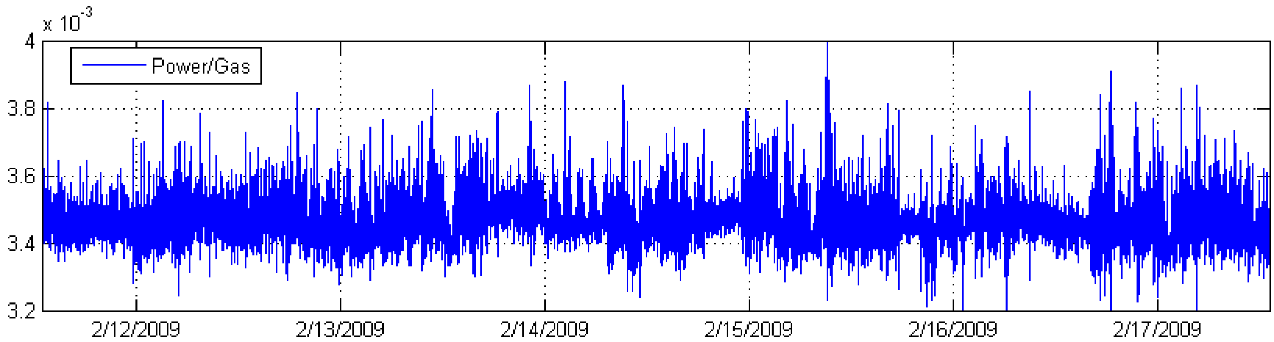

Figure (1): the ratio of active power to gas flow

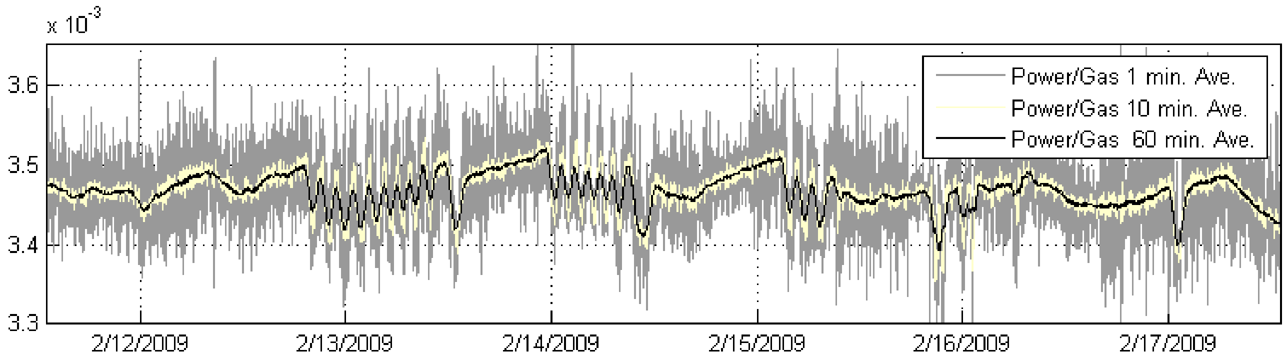

Figure (2): the averaged ratio of power to gas flow

4- Correlation Coefficient

In statistics, correlation (often measured as a correlation coefficient, ρ) indicates the strength and direction of a linear relationship between two random variables. In general statistical usage, correlation or co-relation refers to the departure of two random variables from independence [13].

$$\rho_{X,Y} = \frac{\text{cov}(X,Y)}{\sqrt{\sigma_X \sigma_Y}} \qquad (1)$$

In equation (1) $\rho_{X,Y}$ is the correlation coefficient between X and Y signals. $\text{cov}(X,Y)$ is the covariance matrix between X and Y.

$$\text{cov}(X,Y) = E((X-\mu_X)(Y-\mu_Y)) \qquad (2)$$

Where E is the mathematical expectation and

$$\mu_X = E(X) \qquad (3)$$

In addition, σ_X shows the Variance of X defined as:

$$\sigma_X = \text{cov}(X,X) = E((X-\mu_X)^2) \qquad (4)$$

The absolute value of correlation coefficient shows the strength of dependency and sign shows the direction.

Matlab software computes correlation coefficient between two signal X and Y with the command $corrcoef(X,Y)$.

$corrcoef(X,X) = +1$, $corrcoef(X,-X) = -1$ and if X and Y be two independent variables, $corrcoef(X,Y) = 0$.

5- Study on Potential Agents

Between many researches done for increasing thermal efficiency, usually the air/fuel ratio or excess air ratio is studied as most important agent. However, here we studied more probably effective parameters. These parameters are active and reactive power, air/fuel ratio and gas pressure.

5-1- Active Power

Active power or unit load is one of the most probable parameters that can affect boiler-turbine efficiency. For every unit, there is an optimal load which working on that load, will cause to efficiency be maximized. Figure (3) shows the active power and power/gas relationship for a period of 6 days.

The correlation coefficient between this two parameters is +0.1089. This relatively large absolute value shows the dependency of boiler-turbine efficiency to active power. The positive sign shows the direct relationship. Indeed, working in full load, leads to maximum efficiency and diminishing load will cause to efficiency drops off. Figure (4) shows power/gas and active power for a period of 6-hours. This direct relationship between active power and power/fuel ratio can be distinguished in figure (4).

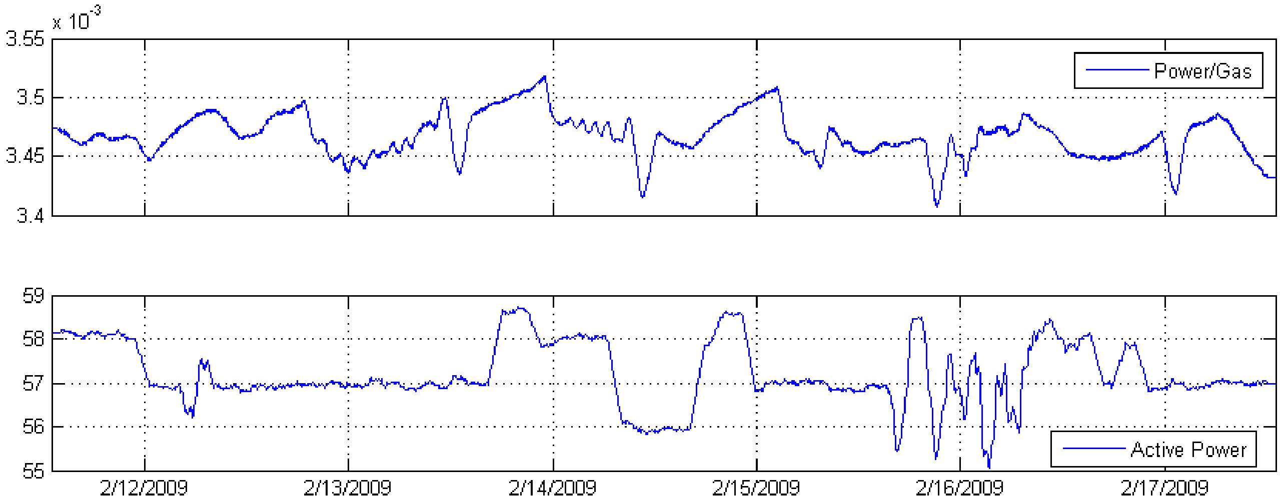

Figure (3): ratio of power to gas flow versus active power

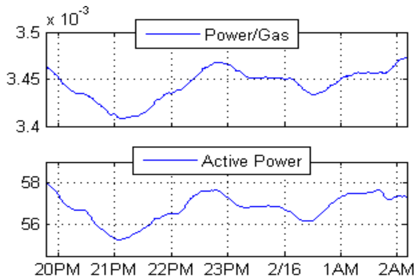

Figure (4): ratio of power/gas vs. load demand in a 6-hour period. The coordination between active power and efficiency can be seen in this period.

5-2- Reactive Power

Another probable parameter that can change the efficiency is reactive power. However, no fuel is burnt for reactive power in power plants; production of reactive power occupies the capacity and can influence efficiency. In this case study, no relationship between efficiency and reactive power is observed. Correlation coefficient is equal to 0.0031, which is very small and negligible.

5-3- Air/Fuel ratio

One of the most important parameters affecting boiler combustion efficiency is air/fuel ratio or equally excess air ratio. For any boiler with a particular construction and fuel characteristics, there is an optimal excess air ratio that thermal efficiency is maximum; with a decrease in the excess air ratio(from optimal point), efficiency will drop because of incomplete combustion. On the other hand, an increase in the excess air ratio will diminish efficiency because of increasing flue gas losses. In this system, historical data illustrates that the boiler is working with insufficient air supply. Consequently, an increase in the excess air ratio (or equally air/fuel ratio) will develop thermal and overall efficiency. Correlation coefficient between boiler-turbine efficiency and air/fuel ratio is 0.4201. Figure (5) demonstrates these two parameters during a 11-hour period. As can be interpreted in this figure, increasing air/fuel ratio will enhance the efficiency.

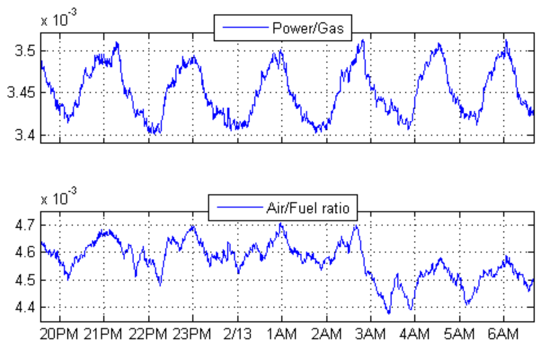

Figure (5): Top: The ratio of Active power on Fuel. Down: Air/Fuel Ratio

5-4- Gas pressure

In first look, the gas pressure cannot affect the boiler-turbine efficiency. The correlation coefficient is -0.089. Relatively large correlation coefficient between these two seems surprising. More attentions show that gas pressure affects air/fuel ratio and changing air/fuel ratio adjust thermal efficiency. Figure (6) shows the relationship between these triple parameters. As figure (6) explains, gas pressure has an inverse effect on air/fuel ratio and air/fuel ratio as discussed before, has direct relationship with efficiency. Correlation coefficient between gas pressure and air/fuel ratio is -0.5593 and between air/fuel ratio and power/gas is 0.4201.

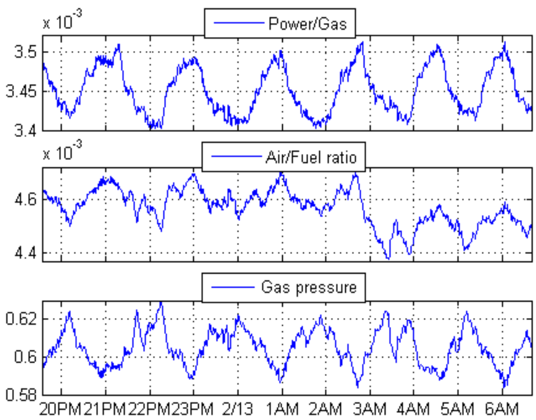

Figure (6): Top: Ratio of power on fuel flow
Middle: Air/Fuel Ratio
Down: Gas pressure

6- Conclusion

Efficiency optimization in power plant is studied. Available data of a gas fired boiler shows air/fuel ratio is the most important parameter affect thermal efficiency. As discussed in this case study, because of incorrect air/fuel regulation table, gas pressure can involve efficiency.

7- References

[1] A. Kusiak, and Z. Song, "Combustion efficiency optimization and virtual testing: A data mining approach," *IEEE Trans. Ind. Inform.*, vol. 2, no. 3, pp. 176–184, Aug. 2006.

[2] Z. Song and A. Kusiak, "Constraint-based control of boiler efficiency: A data-mining approach," *IEEE Trans. Ind. Inform.*, vol. 3, no. 1, feb. 2007.

[3] A. Kusiak and Z. Song, "Clustering-based performance optimization of the boiler–turbine system," *IEEE Trans. Energy Conv.*, vol. 23, no. 2, June 2008.

[4] V. I. Kuprianov, "Applications of a cost-based method of excess air optimization for the improvement of thermal efficiency and environmental performance of steam boilers," Renew. Sustainable Energy Rev., vol. 9, no. 5, pp. 474–498, 2005.

[5] W. Kaewboonsong, and V. I. Kouprianov, "Minimizing fuel and "external" costs for a variable load utility boiler firing fuel oil," Int. J. Thermal Sci., vol. 42, no. 9, pp. 889–895, 2003.

[6] V. I. Kuprianov, and V. Tanetsakunvatana, "Optimization of excess air for the improvement of environmental performance for a 150 MW boiler fired with Thai lignite," Appl. Energy, vol. 74, no. 3, pp. 445-453, 2003.

[7] V. Havlena and J. Findejs, "Application of model predictive control to advanced combustion control," Control Eng. Practice, vol. 13, no. 6, pp. 671–680, 2005.

[8] J. Q. Li, J. Z. Liu, Y. G. Niu, and C. L. Niu, "Online self-optimizing control of coal-fired boiler combustion system," in Proc. IEEE TENCON, Chiang Mai, Thailand, pp. 589–592, 2004.

[9] Y. Y. Nazaruddin, A. N. Aziz and W. Sudibjo, "Improving the performance of industrial boiler using artificial neural network modeling and advanced combustion control," Int. Conf. Control, Automation and Systems, in COEX, Seoul, Korea, Oct. 2008.

[10] R. C. Booth and W. B. Roland, "Neural network-based combustion optimization reduces NOx emissions while improving performance," in Proc. IEEE Industry Applications Dynamic Modeling Control Applications,

Industry Workshop, pp. 1-6. 1998.
[11] S. A. Kalogirou, “Artificial intelligence for the modeling and control of combustion processes: A review,” Progr. Energy Combust. Sci., vol. 29, no. 6, pp. 515–566, 2003.
[12] P. Dockrill, and F. Friedrich, Boilers and Heaters: Improving Energy Efficiency. Office of Energy Efficiency (OEE): Canada, 2001.
[13] http://www.en.wikipedia.org/ wiki/correlation