Simulation Based Data Reconciliation for Mornitoring Power Plant Efficiency

Sangjun Park, Gyunyoung Heo*
Kyung Hee University, Yongin-si, Gyeonggi-do, 446-701, Korea
**Corresponding author: gheo@khu.ac.kr*

1. Introduction

Power plant efficiency is analyzed by using measured values, mass/energy balance principles, and several correlations. Since the measured values can have uncertainty depending on the accuracy of instrumentation, the results of plant efficiency should definitely have uncertainty. The certainty may occur due to either the randomness or the malfunctions of a process. In order to improve the accuracy of efficiency analysis, the data reconciliation (DR) is expected as a good candidate because the mathematical algorithm of the DR is based on the first principles such as mass and energy balance considering the uncertainty of instrumentation. It should be noted that the mass and energy balance model for analyzing power plant efficiency is equivalent to a steady-state simulation of a plant system. Therefore the DR for efficiency analysis necessitates the simulation which can deal with the uncertainty of instrumentation. This study will propose the algorithm of the simulation based DR which is applicable to power plant efficiency monitoring.

2. Methods and Results

2.1 Basic Principles

The data validation that means improving data quality can be attained by elimination of systematic errors and/or by the minimization of the influence of random errors. The random errors are an unavoidable part of any measurement and are characterized by standard deviation. The systematic errors are remarkably greater in magnitude than random errors and if the whole measurement has not to be disvalued, they must be eliminated from the measured data set. If we have several sets of data and the error is deterministically repeated in time, we call it as the systematic error. The most obvious approach may be to adjust the data such that they obey the first principles exactly. The typical representatives are the balance models for mass and energy (the conservation laws) that hold true under general conditions. The basic idea of the DR is, therefore, the adjustment of the measured values in a manner that the reconciled values are as close as possible to the true (unknown) ones on the basis of mass and energy balances. The governing equation of the DR is shown in Equation (1). [1]

$$\boldsymbol{F(x,y,c) = 0}, \tag{1}$$

Where is ***F*** is the vector of model equations, ***x*** is the vector of directly measured variables, ***y*** is the vector of directly unmeasured variables**,** ***c*** is the vector of precisely known parameters.

The reconciled value, x_i' results from the $x_i' = x_i^+ + v_i$ where x_i^+ is the measured value added by adjustments, v_i. The adjustments must satisfy two fundamental conditions:

1) The reconciled values obey ***F(x,y,c) = 0***, we say that they are consistent with the model ***F(x',y',c) = 0***.
2) The adjustments are minimal. Most frequently, one minimizes the weighted sum of squares of the adjustments using the well-known least squares method in Equation (2).

$$\sum (v_i / \sigma_i)^2 = \sum \left(\left(x_i - x_i^+ \right) / \sigma_i \right)^2 \tag{2}$$

The inverse values of the dispersions (squared standard deviations) guarantee that more statistically precise values are less corrected than the less precise ones.

If there are no errors, then no adjustments will be necessary. Therefore, $Q_{\min} = \Sigma (v_i / \sigma_i)^2$ is equal to zero. If only random errors with Gaussian distribution are present, one can show that $Q_{\min}$ is the random variable of χ^2 distribution, and there must hold with probability $(1-\alpha)$: $Q_{\min} < Q_{crit} = \chi^2{}_{(1-\alpha)}(n)$ with n degrees of freedom. If the inequality is not satisfied, the possible presence of a systematic error is considered.

It is universally accepted that any measurement is charged with some errors. The measurement error is defined by Equation (3).

$$x^+ = x + e, \tag{3}$$

where x is the true (unknown) value and e is the measurement error. Information about possible errors in measurement, sometimes referred as uncertainty or maximum error, is indispensable. The uncertainty has the character of a maximum error assumed at the measurement or guaranteed by the manufactures. The uncertainty expressed with the instrument's range is called the class of accuracy.

$$x \in < x^+ - e_{\max} ; x^+ + e_{\max} >, \tag{4}$$

where $e_{\max}$ is the maximum error. In practical DR, we take half of the maximum error as a standard deviation.

2.2 Optimization Model and Algorithm

The algorithm of the DR proposed in the study is basically based on the comparison of the measured values with the expected values from simulations. Generally simulations require the input of boundary conditions as well as the properties of components to calculate the mass and energy balance. The component properties can be obtained from any reference cases such as design materials or acceptance test results. The boundary conditions such as, for example, temperature, pressure, or flowrate of main steam and seawater should be referred on the measured values while considering the uncertainty of each instrumentation. In conclusion, the expected values from a simulation are the heat balance combined current operating conditions with the component properties of the reference case. Since the expected values are taken from the repeated simulations under a reference condition and the measured values are collected from a current condition, their comparison could be also thought as that of a reference heat balance and an aged heat balance.

The algorithm to gain an optimal reconciled dataset y_i is shown in Figure 1. The expected values, x_i which are created from a simulation and the measured values, x_i^+ are calculated by Equation (2). Then, it is decided whether there is any systematic error or not by applying chi-square distribution. The degree of freedom is decided as the number of boundary conditions since other measured values are changed by the boundary conditions. If there is no systematic error, the expected values with the smallest $Q_{\min}$ is chosen as an optimal reconciled dataset. If there is/are systematic error(s), Equation (2) is repeatedly calculated as eliminating the most deviated parameter between an expected and a measured value one by one. This continues until $Q_{\min}$ is less than Q_{crit} . The eliminated parameters are considered as systematic errors, and the random errors have already diminished by the mass and energy balance calculation during simulations.

The parameters which are suspected as systematic errors should be noticed to operators and can be overridden by the expected dataset.

2.3 Implementation

For practical implementation, we utilized PEPSE for the mass and heat balance simulation. A spreadsheet, Excel was used to implement of the proposed algorithm since it enables the database to be connected. This module can be used in the server for monitoring power plant efficiency in a stand-alone manner. [2]

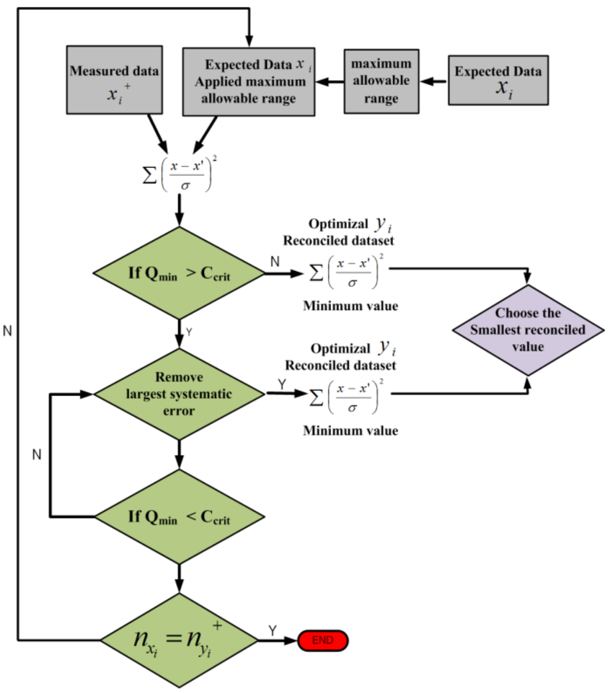

Figure1. Data reconciliation algorithm

3. Conclusions

This study suggests the use of the simulation based DR for finding optimal reconciled dataset for monitoring the efficiency in power plants. Since most of the power plants are applying on-line thermal performance monitoring system, this algorithm can possibly increase the quality of performance management. As long as a simulation model is available, the same algorithm can be applied to any types of process monitoring.

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