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# Performance assessment of thermal power plant load control system based on covariance index

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A B S T R A C T

This paper proposes a novel method of performance assessment for load control system of thermal power unit. Load control system is the most important multivariable control system. It is necessary to monitor and evaluate the performance of it. The performance evaluation index system based on covariance is defined, and the performance evaluation rules are given. In MATLAB, the double input and double output object model of the load control system is established, and the dynamic characteristics of the load control system are analyzed under the BF and TF mode. The simulation data, which is based on the parameters retuning, is used as the "benchmark data", and the simulation data of different controllers are collected as "monitoring data". For most of the time, the thermal power plant is under the coordinated control mode, and the principle and strategy of the two coordinated control are analyzed, and the engineering realization scheme is given. Operation data in different time periods of two different thermal power plants was acquisition and preprocessing respectively. The principle of selecting "benchmark data" is the minimum of pressure parameter. Two data segments were selected as "benchmark data", performance assessment and analysis was carried on the data from other time periods. The results show that the validity and reliability of the method based on the evaluation index. In short, the data of the simulation and the load control system of power plant are used to demonstrate the effectiveness of the method.



## 1. Introduction

At present performance monitoring techniques of multivariable control system have been one of the focuses in the automation field. The research conclusions are mainly based on the minimum variance control method about random performance assessment. For example Desborough and Harris (1993) and Huang and Shah (1997, 1998) introduced minimum variance control principles into multivariable control systems. Harris (1989), Qin (1998) and Harris, Seppala, and Desborough (1999) put forward multivariate system Filter and the Correlation Analysis (FCOR) algorithm. Desborough and Harris (1992) and Huang (2003) applied the minimum variance control method to multivariate feed forward and feedback control system. Ko and Edgar (2004), Zhao, Su, and Chu (2009) and Jelali (2006) introduced linear generalized minimum variance index into multivariable control systems. Yu and Qin (2008a, 2008b), Wang and Wang (2010) and Yin, Ding, and Xie (2014) proposed generalized multivariable control system performance assessment based on output variance limits. However, the above assessment methods need to calculate the correlation matrix, the covariance between output sequence and white noise sequence, and the calculation process is very complex.

To avoid the difficulty of the minimum variance control principles, Harris presented a new control system performance assessment method which only used the closed loop operation data. Because the method's calculation is simple and it is easy to implement, it is effective in actual industrial control applications. Yin, Li, and Gao (2015), Yin and Huang (2015) proposed the index of performance assessment based on covariance benchmark, and further revealed the direction of control performance optimization/deterioration through generalized eigenvalue analysis. Zhang, Zhang, and Yang (2003) applied covariance benchmark to model predictive control performance assessment and monitoring. Li, Ren, and Sheng (2002) and Ma and Jiang (2011) sketched a basic data-driven design framework with necessary modifications under various industrial operating conditions. Huang and Shah (2012), Huang and Jeng (2002), An, Heo, and Chang (2011), Zhang and Fang (1982) and Huang (1998) proposed a data-based covariance benchmark for control performance monitoring and which show that the generalized eigenvalue and the covariance based performance index are invariant to scaling of the data.

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Load control system is one of the most important control systems in thermal power plant. However, the research of load control system performance assessment is very little. Now there is not a reasonable control system performance monitoring system, and the operators only depend on manual analysis data to determine control system performance. It is difficult to adapt to the requirement of thermal power unit. Therefore, researching the performance assessment of the load control system has a great significance. This paper develops a new performance assessment method for thermal power unit load control system, which is based on covariance index of operation data.

The organizational structure of this paper is as follows. In the second section, relationship between the generalized eigenvalues of covariance matrix and statistical inference and performance was derived, the definition of the performance assessment indexes based on the covariance index was included, and also the performance assessment rules were given. In the third section, the structure of the load control object is given, and the four different operation modes and characteristics are analyzed. In the fourth section, the load control system under different operation modes were simulated, under the circumstances of knowing the controlled object model, applying parameter tuning, and the optimal controller was gained, naturally the corresponding output data was the benchmark data, and meanwhile the output data of the system under other controller of different parameters were chosen as monitoring data, the covariance index was calculated and also performance assessment rules were evaluated. Under the boiler follow mode and turbine follow mode, the characteristics of the load control system was analyzed and a comparative analysis was made. In the fifth section, we give the two actual plant operating data, with the principle of the main steam pressure fluctuation minimum and process is the most stable and also optimization of security, "benchmark data" were selected in different operation period of two power plants, based on covariance index and performance assessment rules, operating data for other periods were assessment and analysis.

## 2. Performance assessment algorithm

### 2.1. Covariance-based index

#### 2.1.1. Definition of covariance matrix (Fernandez & Himmelblau, 2004)

The covariance matrix of two-dimensional variable $(X, Y)$ can be marked as $\mathrm{cov}(X, Y)$, which was defined as:

$$\mathrm{cov}(X, Y) = E\{[X - E(X)][Y - E(Y)]\} \tag{1}$$

Then the covariance matrix of two-dimensional variable $X_1$,$X_2$ can be written as:

$$\begin{pmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{pmatrix} \tag{2}$$

Among Eq. (2),

$$\begin{aligned} c_{11} &= E\{[X_1 - E(X_1)]^2\} \\ c_{12} &= E\{[X_1 - E(X_1)][X_2 - E(X_2)]\} \\ c_{21} &= E\{[X_2 - E(X_2)][X_1 - E(X_1)]\} \\ c_{22} &= E\{[X_2 - E(X_2)]^2\} \end{aligned} \tag{3}$$

From the above analogy, the covariance matrix of $n$-dimensional variable $(X_1, X_2, ...X_n)$ can be written as:

$$\begin{pmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & \cdots & c_{nn} \end{pmatrix} \tag{4}$$

Among Eq. (4)

$$c_{ij} = \mathrm{cov}(X_i, X_j) = E\{[X_i - E(X_i)][X_j - E(X_j)]\} \tag{5}$$

#### 2.1.2. Generalized eigenvalue analysis of covariance matrix

Covariance index is used to evaluate the performance of the system, and it is related to the comparison of the covariance of the data between the benchmark period and the monitoring period. In general, the benchmark data was marked as $B$, and the monitoring data was marked as $M$, the maximum value of the following equation:

$$p = \arg\max \frac{p^T \mathrm{cov}(y_M)p}{p^T \mathrm{cov}(y_B)p} \tag{6}$$

Among Eq. (6), $\mathrm{cov}(y_B)$ and $\mathrm{cov}(y_M)$ representing the data and monitoring data in the period of the covariance matrix. Define $\lambda$ as:

$$\lambda = \frac{p^T \mathrm{cov}(y_M)p}{p^T \mathrm{cov}(y_B)p} \tag{7}$$

The formula derivation, get

$$\frac{\partial\lambda(p)}{\partial p} = \frac{2\mathrm{cov}(y_M)p(p^T\mathrm{cov}(y_B)p) - 2(p^T\mathrm{cov}(y_M)p)\mathrm{cov}(y_B)p}{(p^T\mathrm{cov}(y_B)p)^2} \tag{8}$$

Because the maximum value point is satisfied:

$$\frac{\partial\lambda(p)}{\partial p} = 0 \tag{9}$$

we get:

$$\mathrm{cov}(y_M)p = \lambda(p)\mathrm{cov}(y_B)p \tag{10}$$

In Eq. (10) $\lambda$ represents the generalized eigenvalue and $p$ represents the corresponding characteristic vector.

#### 2.1.3. Covariance performance index (McNabb & Qin, 2003, 2005; MacGregor & Kourti, 1995)

Joe et al. defined the covariance based performance assessment index with the operation benchmark data as the reference, and its assessment function form is the covariance matrix determinant of the system output signal:

$$I_v = \frac{|\mathrm{cov}(y_M)|}{|\mathrm{cov}(y_B)|} \tag{11}$$

was marked as the covariance matrix determinant of the benchmark data $B$ and $|\mathrm{cov}(y_M)|$ was marked as the covariance matrix determinant of the data of the monitoring period respectively.

Generally $\mathrm{cov}(y_B)$ and $\mathrm{cov}(y_M)$ are full rank, the generalized eigenvalue analysis can be simplified as a solution to the eigenvalue problem, as shown in the following:

$$\left\{\mathrm{cov}^{-1}(y_B)\cdot\mathrm{cov}(y_M)\right\}p = \lambda p \tag{12}$$

For multivariable processes:

$$\mathrm{cov}(y_M)P = \mathrm{cov}(y_B)P\Lambda \tag{13}$$

In the above Eq. (13), $\Lambda$ is a diagonal matrix, diagonal elements of $\Lambda = diag(\lambda_1, \lambda_2, \cdots, \lambda_q)$ consists of $\lambda_i(i = 1, 2, \cdots, q)$,