Comparative Analysis of False Data Detection Methods at Power Plants ACS TP

S V Mezin
National Research University “MPEI”,
Russia, 111250 Moscow, Krasnokazarmennaya 14

Abstract. The report contains a review of the current detection methods of technological parameters unreliable observations in plant ACS. These methods allow you to substantially improve the quality of control at the station, as well as reduce risks of emergency and abnormal situations. Inaccurate observation presented "emissions", "failures", "breakages", "sinking" and "zero drift" signals. The report discusses the monitoring range makers, unlike binary observations of two values 0 and 1. Comparative analysis of methods, identify the advantages and disadvantages of each method, peculiarities of their application.

1. Introduction
Control and diagnostics systems of thermal and nuclear power plants is not possible without information about the control object. It is formed as a result of numerous measurements of process parameters. Measurement data characterizes the state of the control object. It used a diagnostic system and protection for a decision on further operation of the facility. Control system using the information for generating the control actions, according to established algorithms. Measuring information required to calculate technical-economic indicators (TEI).

Measuring information systems of ACS TP must be timely, complete and accurate. Data inconsistency one of these criteria leads to a decrease in efficiency of operation, malfunctions and accidents of the control object. A significant portion of false triggering of the protection systems due to inadequate information.

Assessment of the reliability of the measuring information, the detection, removal and replacement of unreliable observations are important tasks that enhance the reliability of thermal and nuclear power plants.

2. Description of the IMC failure
Information about the control object is generated as a result of measurements of technological parameters. Further information comes from sensors on information-measuring channels (IMC) to the signal modules, next to PTC, then to the archive station.

Information-measuring channel is the combination of measuring, transmitting and recording equipment used on the transmission way of the measured values of the technological parameter to the computer system.
This report will be considered by the IMC, the observations which take the range of possible values, unlike binary observations, is represented by two values 0 and 1.

Before continuing consideration of methods for assessing the reliability of the information, let consider typical failures of the IMC. Failure – termination of the ability of functional unit to execute predefined functions [2]. The failure of the IMC means that the value of the technological parameter obtained registered equipment differs from the actual value. The value obtained bears false information about the measured parameter. Inadequate information is a result of the failure of the IMC.

"Splash" is a failure, characterized by a transient increase in the measured values with subsequent recovery of the initial values. "Slump" is a failure, characterized by transient decrease of the measured values with subsequent recovery of the initial values. The reasons for "Splashes" and "Slumps" are disturbances in communication lines, disturbances in the power measuring devices, etc.

"Breakage" is the failure that occurs in the case that the terminal equipment does not register the value of the measured parameter. The reason for the "breakage" can be not-directly open lines of communication, failure of sensor or receiving signal module failure.

The next failure is called "Freezing". In the event of failure of the IMC because of "Freezing" the measured value continues to change, decreases the standard deviation of the process and change the spectrum of the signal. The signal continues to fluctuate in the range, are characteristic for the normal mode of operation of the IMC, but its value does not reflect the true value of the measurand.

The most difficult to detect a failure is "zero drift". The signal in this case varies with the same frequency and the same value of standard deviation relative to the average. But the mathematical expectation value of the signal gradually deviates from the true value.

3. Methods for the detection of IMC failure

3.1. The use of redundancy

All methods of assessing the reliability of information using a certain kind of redundancy. They distinguish structural, time and information redundancy [3].

Structural redundancy requires the introduction of additional elements in the information system. In other words, the structural redundancy is the redundancy of the system elements. Temporal redundancy is a multiple of one stage of the processing of information. The results obtained need to compare and make a conclusion based on some statistical test on the reliability of the information. For example, many times the experiments were conducted on the measurement values of technological parameter. If the results are within acceptable limits, then reliable value is possible to take the mathematical expectation obtained from the results of experiments.

The last type of redundancy is information redundancy. It can be natural and artificial. Natural redundancy reflects the objectively existing relations between the parameters of the information system. This redundancy can be represented by the balance equations (conservation laws of matter, energy, momentum). Artificial information redundancy in the individual elements of the system based on additional calculations of the parameters associated with the data processing algorithms. Artificial information redundancy could reflect a relationship between the parameters of the information system using the regression equation.

3.2. Admittance control method

Admittance control method [4] is used for filtering gross errors of measurement. The method imposes restrictions on the values of the observations received from the transmitter for IMC:

\[ y_i^b \leq y_i \leq y_i^u, \]  

where \( y_i^b \) and \( y_i^u \) are the lower and upper bound of the range of possible signal values.
The accuracy of the observations is estimated by results of conditions check (1). In case the condition is false, the monitoring parameter in a given time is replaced by presumed reliable. In the simplest case, as reliable observations were used the last observation that meets the condition (1).

Borders $y_i^u$ and $y_i^w$ for stationary processes are constants and can be obtained from statistical analysis of the distribution function $y$ for the accepted confidence probability $P$. For non-stationary random processes the boundaries of the range are functions of time. The problem of finding these functions is much more complicated. In this case, the boundaries must be represented as a sum of the absolute statistical error estimation of the mathematical expectation $\Delta_m$ and the evaluation $\tilde{m}_i(t)$.

$$y^u(t) = \tilde{m}_i(t) - \Delta_m$$  \hspace{1cm} (2)

$$y^w(t) = \tilde{m}_i(t) + \Delta_m$$  \hspace{1cm} (3)

The mathematical expectation estimate $\tilde{m}_i(t)$ requires further analysis of process $y(t)$.

3.3. Admittance control method of the signal change rate

Admittance control method of the signal change rate [4] limits the rate of change of the measured parameter above. This is justified by the fact that most of the processes are inertial. Therefore, the maximum rate of change of the options may be limited. Therefore, may be limited by the rate of change of the signal measurement information through this channel:

$$\frac{dy}{dt} \approx \frac{y_i - y_{i-1}}{\Delta t} \leq v_i,$$  \hspace{1cm} (4)

where $v_i$ - the estimate of the maximum possible rate of the signal change; $\frac{dy}{dt}$; $\Delta t$ – the quantization interval by time.

The accuracy is evaluated on the results of checking condition (4). This method complements the method of admittance control parameter, and therefore, they are often carried and used together.

3.4. Hardware redundancy of IMC

Hardware redundancy demonstrates the structural redundancy of the system. Reservations are subject to very important elements of the system. The system introduces additional elements performing the same functions, and redundant elements [3, 5].

Methods for assessing the reliability of information used in hardware reservation of the measuring sensors based on the information received from these sensors. Such methods are called methods of group signals comparator control (CCG). With the help of CCG evaluated the accuracy of the group of signals at two or more values obtained by independent measurements. We are talking about control or about calculating the most probable parameter values for multiple measurements, based on the laws of mathematical statistics.

If parallel measurements are made by two sensors, to assess the accuracy of the information compares the readings of both sensors. The differences between the readings exceeding a predefined value, is a sign of partial failure. In this case, the following condition is checked:

$$|y_i^{(1)} - y_i^{(2)}| \leq C,$$  \hspace{1cm} (5)

where $y_i^{(1)}$ – first sensor measurement, $y_i^{(2)}$ – second sensor measurement, $i$ – measurement number, $C$ – the predefined limit value of the difference between the readings.

The violation of condition (5) is a sign of IMC failure. This is not possible to determine what the IMC was denied. If the measurement is made in parallel three or more sensors, this drawback can be avoided. For the validation of observations used criterion (6):

$$|y_i^{(j)} - y_i| \leq C.$$  \hspace{1cm} (6)
where \( y_{ij} \) – \( j \)-th sensor measurement, \( \bar{y}_i \) – the mean value of the sensors measurements, \( i \) – measurement number, \( C \) – the predefined limit value of the difference between the observations and the mean value.

3.5. **Pseudo-redundancy of IMC**

The comparator control idea formed the basis of the method of assessing the reliability of information using pseudoredundancy of IMC. The advantage of CCG is that it allows to estimate the reliability of measurement results for any possible mode of operation of power equipment. If hardware redundancy for this IMC was not provided, it is necessary to find a channel with similar dynamics of changes in values. Consider the method by the example of the temperature distribution of exhaust gases output of the gas turbine (see figure 1).

![Figure 1. The temperature distribution of exhaust gases output of the gas turbine.](image)

In figure 1 the abscissa shows the temperature range 0-700 °C percentage. Each trend corresponds to the temperature of the flue gas, checked one of the sensors installed in the cross section of the gas turbine at the last stage.

In this example, each temperature sensor carries information about the temperature field at a given point of the cross section. But since two sensors are in close proximity, and the testimony they will give similar. The trends one can observe the same trend with a difference between the sensor readings of a few degrees. At some point of time the trend of the testimony of one of the sensors begins to stand out from the rest. Assume that the sensor is broken, and logged information about the temperature of the gas unreliable.

Thus, we observe the "artificial" redundancy sensor. When violations in the work of one of the IMC, you can rely on the testimony of another. The values of the statistical estimates in this case would be the following:

\[
\begin{align*}
\tilde{m}_\Delta & \rightarrow const, \\
\tilde{\sigma}_\Delta & \rightarrow \min, \\
\tilde{r}_{xy} & \rightarrow 1,
\end{align*}
\]

where \( x \) – observations of the original measuring sensor; \( y \) – monitoring a redundant of a measuring sensor.

\[
\Delta_i = x_i - y_i,
\]

\( x_i \) - sensor \( x \) observation at \( t_i \) time; \( y_i \) - sensor \( y \) observation at \( t_i \) time.

Statistical evaluations (7)-(9) serve as a criterion for the choice of reserving the channel. Assessment of the reliability of observations is similar to CCG.
When using pseudoredundancy supposed that the dynamics of the two channels is similar and unchanged in time. But sometimes this assumption is not true. Consider the example of temperature distribution of exhaust gases output of the gas turbine are given in Figure 2.

In Figure 2 the abscissa shows the temperature range 0-700 °C percentage. Each trend corresponds to the temperature of the flue gas, checked one of the sensors installed in the cross section of the gas turbine at the last stage.

Dynamics of two sensors on a first time interval varies significantly, but on the second time interval observations have close values.

3.6. Methods based on the probabilistic connection of measured parameters

Methods of assessing the observation reliability and diagnosis of the IMC failure, based on the relationship of the measured parameters, use two types of models: models built using a probabilistic relationship between parameters of the functional relationship. The mathematical model represented by equations of communication of the measured variables, constraints, and algorithmic rules.

To construct a mathematical model using probability relationships can be used in regression or correlation analysis [6]. The regression equation in matrix form is represented by the expression (11):

\[ Y = X\beta + N, \]

where \( Y_{(n \times 1)} \) – vector of response observations; \( X_{(n \times m)} \) – given a factors matrix; \( \beta_{(m \times 1)} \) – parameters vector; \( N_{(n \times 1)} \) – errors vector; \( n \) – the size of the experiment; \( m \) – number of factors; the first index in brackets \((n \times m)\) – the number of rows; second index is number of columns.

The predicted regression equation obtained from the results of experimental data processing, is represented by the expression (12):

\[ \hat{Y}_{pred} = XB, \]

where \( \hat{Y}_{(n \times 1)} \) – the vector of predicted response values; \( B_{(m \times 1)} \) – a column-vector of parameter estimates of the regression equation.

Equation (12) establishes a relationship between the factors and the predictable response, which can be used one of the measured parameters. The discrepancy between the predicted response and the actual, beyond a set allowable value, is a sign of irregularities in the work of the IMC.
The equation can be obtained not only on the basis of regression and correlation analysis. For this purpose, can be used neural networks [7], and nonlinear methods based on the theory of random functions [8].

3.7. Methods based on the functional relationship of the measured parameters.

For failure IMC diagnostics the equations of variables of the form (13) can be used:

\[ F_j(X) = F_j(x_1, x_2, \ldots, x_n) = 0, \quad j = 1, 2, \ldots, m. \]  

(13)

Equations (13) can be derived from balance relations, equations describing the approximation of the dependencies. Equations (13) is valid only for the authentic, the true values of its member variables \( X \). In practice, the equations are not met, because the values \( X \) contain measurement errors:

\[ \bar{x}_i = x_i + \Delta x_i, i = 1, 2, K, n \]  

(14)

where \( \bar{x}_i \) – the value of \( i \)-th parameter received in the measurement result.

According to (14) equation (13) takes the form:

\[ F_j(X + \Delta X) = \Delta F_j, \]  

(15)

Values of the errors \( \Delta x_i \) can be found by solving the task of optimal distribution of errors. The criterion of optimization is:

\[ \sum_{i=1}^{n} p_i (\Delta x_i)^2 \rightarrow \min, \]  

(16)

where \( p_i \) – weights.

The resulting calculation error may be used as corrections to the measurement results.

To detect failures of the IMC by using a method based on functional relationship of the measured parameters, it is necessary to calculate and compare the obtained values with the maximum permissible \( \Delta F_j^* \):

\[ |\Delta F_j| \leq \Delta F_j^*. \]  

(17)

In the case that condition (17) holds for all the equations, the IMC failures do not exist.

3.8. Artificial intelligence methods

Artificial intelligence methods include algorithms that reflect the logic of human reasoning in one form or another. These include algorithms based on neural networks, fuzzy logic, expert systems and others. These methods are versatile and find application in various fields of science and technology [7]. They can be applied to assess the reliability of observations. Look at some of them.

A neural network is a special computing structures, with the property of learning. They show a complex nonlinear dependence between the parameters of the system. The use of neural networks for estimation of accuracy of observations can be constructed by the method based on the probabilistic relationships of the measured parameters [8, 9].

Mathematical fuzzy logic is used to formalize human experience while addressing the complex task of analysis and decision-making. Fuzzy logic algorithms have found application in problems of control, diagnostics of the equipment, algorithms of indirect control of parameters measured [9]. Fuzzy logic can also be used to build models of measured parameters connection.

The expert system used to diagnose the condition of equipment and the preparation of decisions in the management of complex systems based on the recommendations of experts. Expert systems are computer programs that use logical inference based on expert knowledge for decision-making. Expert systems are used for non-formalizable tasks. To assess the reliability of observations can be used by an expert system, built on the basis of logic operation, putting diagnosis for ACS TP information subsystem.
4. Comparative analysis of methods

Consider the features of each method and carry out their comparative analysis. Let's start with the methods based on the relationship of the measured parameters.

To use methods of accuracy assessment observations based on the probabilistic relationships of the parameters, it is necessary to solve a number of problems. At construction of mathematical models, an important task is the correct choice of the factors \( X \) influencing the response \( Y \). As the object of control during operation changes the characteristics required to periodically recalculate the mathematical model. The reasons for this can be slagging of heating surfaces, the deposition of salts on heat exchange surfaces, etc. Change the value of one factor \( X \) not immediately leads to a change in response \( Y \). In this connection it is necessary to consider the dynamics of the control object. An important task is to evaluate the amount of information contained in the training set (data used to compute the parameters of the mathematical model). In the case of incorrect estimates, the resulting mathematical model may not accurately reflect the relationship between the factors and response function. This task should be given particular attention if the model is evaluated using data from steady-state mode in this mode, the factors change in a very narrow range. If the training sample contains inaccurate observation, it is necessary that the algorithm was robust against them. Depending on which mathematical models are used, there may be additional difficulties in the analysis of the reliability of observations.

The use of methods for assessing the reliability of observations, based on the functional relationship of the parameters is more challenging due to the high complexity of mathematical models of thermal power facilities. Model complexity depends on the considered system. Many models are dynamic, nonlinear, and have distributed parameters. To model for some process parameters (e.g. flue gas temperature at the outlet of the gas turbine) is difficult or the resulting model is unnecessarily complicated and difficult to apply. Functional dependencies can include parameters that must be obtained from experiment, and the values in the operation of the equipment (e.g., thermal resistance of heating surface). Therefore, the model should be periodically reevaluated. In case of any violations in the work of power equipment, affect the relationship between the parameters of the model cannot give an adequate description of the situation: either there's a failure in the power equipment, or observations of IMC unreliable. This issue is an important disadvantage of methods based on statistical and functional relationship of the measured parameters.

The use of methods, built on the information redundancy obtained through IMC hardware redundancy, is a reliable way of assessing the reliability of observations. The disadvantage of this method is the need to increase the number of IMC or their components.

The use of IMC pseudoredundancy to assess the reliability of observation and diagnosis of IMC failures presents some difficulties, discussed in paragraph 3.5. This method of fault diagnosis can be used for channels, in accordance which can be picked up pseudoredundant channel. Artificial intelligence methods do not provide a complete solution for assessing the reliability of observation and diagnosis of the IMC failure. They can be used as an auxiliary to the other considered methods.

Methods of IMC fault diagnosis, based on the analysis of observations of only one IMC are the most versatile. These methods include the admittance control method and tolerance control the rate of change of the signal. In order to use the method of admittance control, it is necessary to correctly estimate the expected signal at each point in time. This requires to explore the change process parameter and to determine the model of [10]. In order to assess the limits of the range of values necessary to investigate the random component of the process. For this purpose, can be used the theory of time series. It is studying the signal changes in time and predicts its value at a specified interval ahead. Studying of changes in the past, can trace its tendencies and to predict its future behavior, to find its expected value.
5. Conclusion
The methods for assessing the reliability of observation and diagnosis of the IMC failure have different advantages and disadvantages, which limit their scope. The most reliable is the method of using the measuring similar information and reserve the IMC. But this method requires the introduction of new elements into the structure of the system. If there are channels with dynamics close to the original channel, you can use pseudoredundancy. The most versatile are methods for evaluating the validity of observations based on the analysis of a single IMC. This includes methods admittance control parameters and tolerance control the rate of change of the parameters. These techniques are most widely used for estimation of accuracy of observations in the automated control systems of heat power objects.

Abbreviations
ACS TP — automatic control system of technological process;
CCG - group signals comparator control;
IMC - information-measuring channel;
PTC – program-technical complex;
TEI - technical-economic indicators.

References
[1] Braganec S. A., Savchits V. A., Sevastyanov, B.G. Improving the reliability of measurement information // Industrial ACS and controllers. M: Nauchtekhlitizdat, 2011. No. 2. S. 46-49.
[2] IEC 60050-191. International Electrotechnical Vocabulary – Chapter 191: Dependability and quality of service.
[3] Gromov Yu. Yu., Drachev V. A., Martem'yanov Yu. F., Voytyuk, V. V., Gromova A. Y. Control and increase the reliability of information in the functioning of the IS // Information and security. 2010 No. 2. P. 227-232.
[4] Dudnikov E. G., Kazakov V. A., Sofieva Yu. N., Sofiev A. E., Tsirlin, A. M. Automatic control in the chemical industry: Textbook for high schools. M.: Chemistry, 1987. p 368.
[5] Harutyunyan, T. M. Development of methods for the measurement of condensers of power plants according to criteria of reliability and cost-effectiveness: dissertation of candidate of technical Sciences. M.: MPEI TU, 2009. 169 p.
[6] Pikina G. A., Shchederkina T.E., Volgin V. V. Identification of control objects in a power system. M.: MPEI Publishing house, 2011. 224 p.
[7] Krug P. G. Neural networks and Neurocomputers: textbook for the course "Microprocessors". M.: Publishing house of MEI, 2002. 176 p.
[8] Kolchev K. K., Mezin S.V. Assessment of the reliability of observations by using ARIMA-models // Vestnik MPEI. – 2015. – No. 3. – S. 28-34.
[9] Sobolev O. S. On the application of artificial intelligence methods in control systems // Industrial ACS and controllers. M: Nauchtekhlitizdat, 2003. No. 12. P. 35-36.
[10] Volgin V. V., Karimov R. N. Evaluation of correlation functions in industrial control systems. M.: Energiya, 1979. 80 C.