Standardization on evaluating instrumentation drift of safety protection system as an industrial guideline in Japan

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Abstract: The instrumentation drift is particularly important for the safety design of reactor protection system because the instrumentation drift will grow with the .continuation of plant operation. The subject of this paper is how to evaluate the growth of instrumentation drift with the extension of reactor operation period more than the traditional practice of one year operation in Japan. In this paper, condensed review is first made on the process of establishing an industrial guideline of evaluating instrumentation drift of safety protection system. The analysis procedure to evaluate instrumentation drift from the calibration data and how to evaluate the effect of instrumentation drift on the set point of the safety instrumentation are also presented in this paper.

Keywords: safety protection systems; instrumentation drift; industrial standard

1 Introduction

There are various process parameters in the safety protection system of nuclear power plant such as temperature, pressure and flow, which serve to ensure reliable safety shutdown of nuclear power plant in the event of plant transients and accident. Those plant parameters are measured by proper detectors and the measured parameters are then converted into electric signals which are used to initiate reactor trip and to actuate the engineered safety system. The set-point value of such instrumentation to generate an actuation signal of reactor protection system and engineered safety system should be designed so that the plant response at the design basis events should be within the permitted range of safety analysis of nuclear power plant. The allowance range of instrumentation important to nuclear safety is evaluated by the plant operator (licensees) and permitted by the national regulation of nuclear power plant.

In determining the set-points of such plant parameters important to nuclear safety, the measurement uncertainties should be considered so that an actuation signal can be generated without exceeding the designed set-point. In this respect, instrumentation drift should be considered as a major factor to cause measurement uncertainty. Instrumentation drift is gradual and continuous deviations of measured instrumentation value from the true value with the continuation of plant operation.

The licensees of nuclear power plant have to control the measurement uncertainty including drift by calibrating the instrumentations during plant outage so that they will not exceed the safety limit set by the safety analysis.

In Japan, the reactor operation period of commercial power reactor had been traditionally limited to 13 months in maximum by the national law of electric power industry which orders to stop the power operation once a year for regular maintenance. This is the reason why the nuclear power plants in Japan cannot continue full power operation until sixteen months, twenty months or twenty four months like the normal practice of long reactor operating period in U.S.A., France, South Korea, *etc*. However, the revision of traditionally conservative regulatory rule for nuclear power plant operation and maintenance

Received date: July 2, 2010
(Revised date: February 17, 2011)

was determined by Nuclear and Industrial Safety Agency(NISA) by the introduction of, what is called "New Inspection System" in 2008 [1]. According to the new inspection system set by NISA in Japan, the utilities will be allowed to determine intervals of continuous plant operation by more flexible manner as long as the utility companies introduce the improved maintenance management program. Since then efforts have been initiated by Japanese utility companies, to build up a mechanism that promotes continuous improvement of maintenance management.

As for the calibration method of the instrumentation important to nuclear reactor safety, the evaluation method of instrumentation drift utilized by individual utilities in Japan had been studied from December 2005 to September 2006. After then, a proposal was made by this utility group that standard calibration method should be established as the industrial guideline which takes into account of changed calibration intervals of safety instrumentations (the case of expanding the calibration interval is major interest for extended reactor operation.)

The Japan Electric Association had responded to this utilities' proposal, by starting to investigation on the codes and standards both in Japan and abroad regarding instrumentation drift, in order to present a desirable industrial guideline applicable to the nuclear power plants in Japan. As a result, the Japan Electric Association has established the guideline JEAG4621 [2] in 2007, as an industrial guideline in Japan to evaluate instrumentation drift for safety protection system of nuclear power plant. The process of establishing the JEAG4621 and the employed methodology are introduced in this report.

2 Process of establishing JEAG4621

The authors of this paper had started the investigation by setting up a task force within the Committee of Nuclear Code and Standard of the Japan Electric Association. For the start of investigation, they decided to refer the current version of the Electric Power Research Institute's Guidelines for Instrument Calibration Extension/Reduction which is normally referred as EPRI TR103335-R1 [3], because this guidelines had been established in early 1990's in the U.S.A. and since then it has been offered the valid evaluation methodology for instrument drift with sufficient application records. They have also investigated evaluation methods of instrument drift, which were used by several U.S. utilities in applying for an extension of outage intervals. The authors' proposed draft guideline was approved after the voting at the Committee of Nuclear Code and Standard in the Japan Electric Association and then approved by the committee followed by the public comments in Japan before its official publication as JEAG4621 in 2007.

3 Evaluation methodology of instrumentation drift

The procedure steps of the evaluation method of instrumentation drift used in JEAG4621 are shown in Fig.1. The details of individual procedural steps of the evaluation method are described one by one in this chapter.

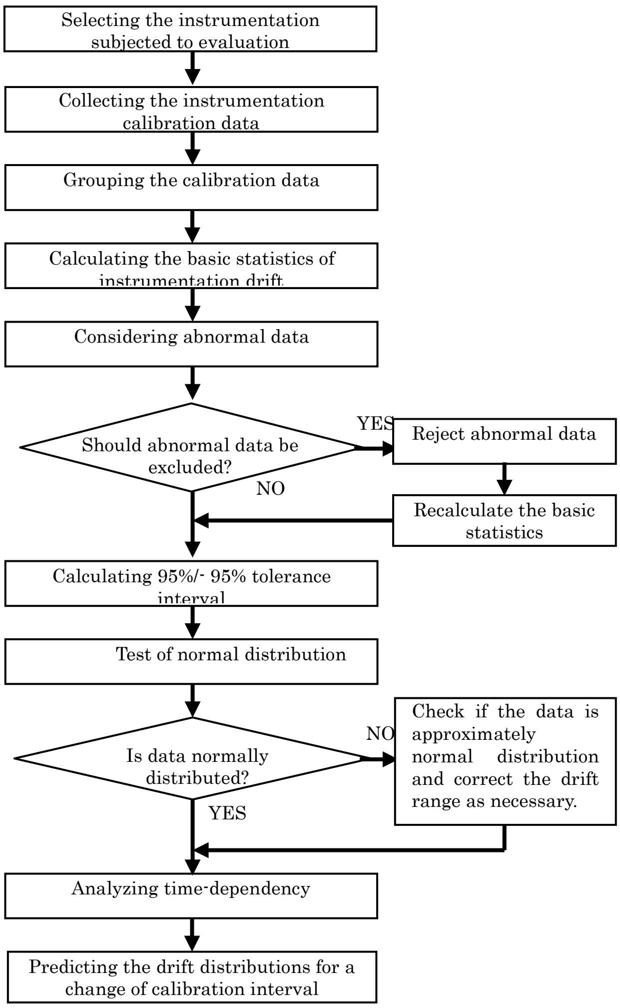

Fig.1 Evaluation method of instrumentation drift.

3.1 Selecting the instrumentation subjected to evaluation

The instruments used for safety protection system can be divided into two types: (a)Some instruments are used to detect continuous fluctuations and changes of parameters (*ex*. pressure/differential pressure transmitter or computing unit), while (b) the others only show the change of condition as ON/Off state. For the former type (a) of instrumentation, the instrumentation values which can affect the result of safety analysis are selected for the drift evaluation.

In addition, the instrumentation to meet with the following conditions is excluded from the evaluation:

- Instrumentation for which periodic calibrations are performed in service or are used only during plant startup/shutdown.
  (*ex*. nuclear instrumentation),
- Instrumentations, which are supposed to have negligible drifts throughout the service period (*ex*. temperature detectors, limit switches and rotation indicators), and
- Digital instrumentation (software)

The instrumentation which is not used in the safety protection system was excluded from the evaluation since their measurement uncertainty has little impact on the safety functions of nuclear power plant.

3.2 Collecting the instrumentation calibration data

According to a theorem of statistics, it is said that if a large number of samples is taken (typically the sample number n is equal to 30 or greater than 30) then the distribution function of the samples is considered to be approximately normal distribution. From this it can be said that the entire population represented by the available samples would like to be defined as normal distribution, the sample size should be equal to 30 or greater than 30. In such a case where a new type of instrumentation is adopted or the sample size is less than 30, the evaluation of drift should be performed not by the method used in this guideline but by referring to the data from shop tests or by other methods.

3.3 Grouping the calibration data

By treating a group of instrumentation which has similar character as a single group, a sufficient amount of data can be obtained and thus a high level of reliability can be assured and the effect of abnormal data can be reduced from the statistical viewpoint.

In grouping instrumentations, it is important to understand correctly the characteristics of the population by considering the manufacturers, instrumentation models, signal types, attributes, measurement ranges, calibration points, operating environment and calibration methods. Concretely the following procedure is recommended in this respect;

(1) Regarding detectors and transmitters, those of the same model (i.e., the same manufacturer with the same measurement principle and structure) for the same measuring objects and the same measuring amount should be classified as the same group.

(2) Those instrumentation other than detectors and transmitters can be divided into two categories: (i)Those that are independent from measuring amounts and measuring objects such as computing units,, and (ii)those that are dependent on measuring amounts such as resistance-voltage converters. Among those instrumentations, those of the same model can be classified as the same group since the instrumentation of the same model may show similar characteristics.

(3) It is also recommended that the instrumentation of other plants with the same conditions can be grouped as the same one.

3.4 Calculating the basic statistics of instrumentation drift

The method for calculating the basic statistics (*e.g.*, average value and standard deviation) is shown below:

(1) The value of drift in percentage at each time point of calibration is given by the following equation:

$$Drift(\%) = \frac{\left(D_{bc}^{n+1} - D_{ac}^{n}\right)}{MS} \times 100 \qquad (1)$$

where

D_{bc}^{n+1} : The measured data at the (n+1)-th time point before calibration,

D_{ac}^{n} : The measured data at the n-th time point after calibration, and

MS : Measured time span.

(2) Calibration intervals are calculated according to the dates of calibration.

(3) Each calibration points for a grouped instrumentation is treated as a single set and then the number of data points, average, standard deviation (sample) and distribution (sample) are calculated.

3.5 Considering abnormal data

If there is an abnormal data in the observed among the drift data in each group and it is sure that this is caused by human error in transcription, excluding this data from the group as outlier is reasonable. However, if the cause of an abnormal data cannot be identified, trends of degradation common in the concerned group of instrumentation values may disappear by excluding this abnormal data as outlier. In order to avoid the possibility that the exclusion of abnormal data would skew the result of drift analysis, null hypothesis test by Smirnov-Grubbs Test is generally applicable to the evaluation of outliers.

3.6 Calculation of drift distribution

In accordance with the statement in Regulatory Guide 1.105, Revision 3, Set-points for Safety-Related Instrumentation [4], the span of drift distribution which includes 95% of drift data points with a 95% confidence score is determined by the following equation:

Span of drift distribution ＝ （*absolute value of average*） ＋ k × （*standard deviation*） (2)

The tolerance factor for 95％/95% k in Eq.(2) is given by

$$k = \sqrt{\frac{(n-1)\left(1+\frac{1}{n}\right)Z^2_{(1-p)/2}}{\chi^2_{\gamma,n-1}}} \tag{3}$$

where:

n : number of sample data,

$Z_{(1-p)/2}$: critical value of normal distribution against upper probability (1-p)/2, and

$\chi^2_{\gamma,n-1}$: χ^2 value for upper probability γ and degree of freedom n-1.

Regarding the group of instrumentations which have multiple calibration points such as transmitters, the basic drift statistics and drift distributions are calculated for each calibration points, and then the maximum drift distribution is treated as the drift distribution for this group of instrumentations.

3.7 Test of normal distribution

The above statistical processing is assumed that the drift data is normally distributed. In this respect, null hypothesis test for normal distribution is made by Chi-Squared (χ^2) test, Goodness of Fit Test, the other test methods which are generally applied for normality test.

The assumption of normality is often denied as a result of the above stated normality test. However, even in such a case, the most of the data may distribute around the average value. Therefore, the histogram of instrumentation drift data should be superimposed on the normal distribution curve based on the average value and standard deviation of the original sample data, in order to confirm that the concerned distribution can be approximated as normal distribution.

With the normal distribution, 95.45% of data are included within the range of doubling the standard deviations. So, if 95.45% of data are not included in the double range of standard deviations, you should determine the boundary value wherein 95.45% of drift data are included in order to decide the following correction factor α.

$$\alpha = \frac{(boundary \quad value)}{2 \times (standard \quad deviation)} \tag{4}$$

The drift distribution is then corrected according to the following equation:

Drift distribution ＝ （*Absolute value of average*） ＋ k ×α× （*Standard deviation*） (5)

3.8 Analyzing time-dependency

In planning to change instrumentation calibration intervals, it is necessary to evaluate the effect of a changed interval on the instrumentation drift. In this respect, the time dependency of the instrumentation drift is evaluated by the following procedure:

(1) Create a scatter plot with the calibration intervals in the X-axis while the drift value in the Y-axis, and perform regression analysis to obtain the linear regression line by means of the least square method. If the correlation coefficient "R" is equal or larger than 0.3, the bias drift components (average) of the concerned instrumentation group are considered to have the time dependency.

(2) Similarly, if the correlation coefficient "R" is 0.3 or larger in the scatter plot with calibration intervals in the X-axis while absolute values of drift in the Y-axis, the random drift components (standard deviation) of the concerned instrumentation group are considered to have the time dependency.

3.9 Predicting the drift distributions after a change of calibration interval

Given that the bias (average) or random drift components (standard deviation) of each instrumentation group have the time-dependency, there is a linear relationship between calibration intervals and drift amounts. The average value and standard deviation after changing the calibration intervals are calculated by the following equation:

$$[\mathit{Value\ after\ changing\ calibration\ intervals}] = [\mathit{Value\ obtained\ from\ the\ current\ data}] \times \frac{[\mathit{Calibration\ intervals\ after\ a\ change}]}{[\mathit{Current\ calibration\ intervals}]} \quad (6)$$

On the other hand, if there is no time dependency, it is assumed that the same drift distribution as the current one will occur after calibration interval changed. In such a case, the distribution is proportional to the calibration intervals, and the standard deviation will be proportional to the square root of the value. Accordingly, the average value and standard deviation after changing calibration intervals are calculated by the following equation:

$$[\mathit{Value\ after\ changing\ calibration\ intervals}] = [\mathit{Value\ obtained\ from\ the\ current\ data}] \times \sqrt{\frac{[\mathit{Calibration\ intervals\ after\ a\ change}]}{[\mathit{Current\ calibration\ intervals}]}} \quad (7)$$

3.10 Evaluating the effect on the set points of safety protection system

The uncertainty of an instrumentation loop as illustrated in Fig.2 can be calculated by combining instrument-specific uncertainties (the uncertainties by the specification of the instrumentation model predetermined by the manufacturer) and the drift distribution after changing calibration intervals.

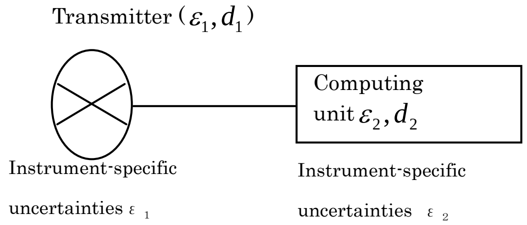

Fig.2 Example for an instrumentation loop consisting of transmitter and computing unit.

The combined uncertainty of the instrumentation loop for Fig. 2 is given by the following equation.

$$(\mathit{Combined\ uncertainty\ of\ instrumentation\ loop}) = \sqrt{\varepsilon_1^2 + d_1^2 + \varepsilon_2^2 + d_2^2} \quad (8)$$

where

ε_1: *instrum*ent-specific uncertainties of transmitter,
d_1: drift distribution of transmitter,
ε_2: Instrument-specific uncertainties of computing unit, and
d_2: drift distribution of computing unit.

Finally as illustrated in Fig.3, it should be confirmed that the combined uncertainty for an instrumentation loop does not exceed the design uncertainties for the individual instrumentations. This means that the combined uncertainty given by Eq. (8) should be less than the designed uncertainty of the difference between the safety limit given by safety analysis and the set point of safety protection system.

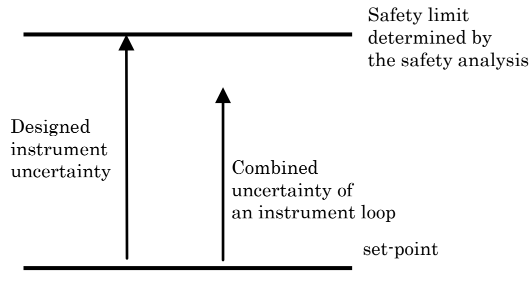

Fig.3 Evaluating the effect on the safety system set-points.

4 Conclusions

How to evaluate instrumentation drift accurately is an important issue for the process control engineering in general. In case of nuclear power plant, this is particularly important for the safety design of reactor protection system, because the instrumentation drift will grow with the continuation of plant operation. Concretely at issue is how to evaluate the growth of instrumentation drift with the extension of reactor operation period more than the traditional practice of one year power operation in Japan. In this paper, condensed review was first made on the process of establishing an industrial guideline of evaluating instrumentation drift of safety protection system as JEAG4621 by Japan Electric Association. The summary of analysis procedure to evaluate instrumentation drift from the calibration data and how to evaluate the effect of instrumentation drift on the set point of the safety instrumentation as given by the guideline are also given in this paper.

References

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