Improvement of Temperature Uncertainty Calculation Methodology for the Plant Protection System

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1. Introduction

Trip setpoints for the plant protection system (PPS) should be selected to provide sufficient allowance between the trip setpoint and the safety limit [1-3]. The analytical limit (AL), which is a kind of analysis setpoint assumed in safety analysis, ensures that the process variable does not exceed the safety limit during design basis events. However, the AL may not be set into the PPS since the PPS channel uncertainty is not reflected in the AL. Thus, the total channel uncertainty should be incorporated into the trip setpoint [2-3]. The total channel uncertainty of the safety instrumentation and control (I&C) system channel is categorized into the measurement channel uncertainty including the transmitter and the signal processing device and the PPS cabinet uncertainty.

The total channel uncertainty is calculated by two combination methods. One is a statistical combination method of square root sum of squares (SRSS) that combines random and independent uncertainties. The other is an algebraic summation method that combines non-random and dependent uncertainties. Since the temperature effect of the PPS cabinet for the Optimized Power Reactor 1000 (OPR1000) has been exceptionally considered as a non-random uncertainty, the PPS cabinet uncertainty has been calculated adding the temperature effect to the result combined by SRSS for all the remaining uncertainties. However, the temperature effects of the measurement channel are combined with SRSS because they are considered as non-random uncertainties.

Since the digitalized PPS applied to the OPR1000 had no sufficient operating experience, the algebraic summation method was used to conservatively combine the temperature effect with other uncertainty factors. Although this approach can obtain the more conservative PPS uncertainty, the method causes inconsistency in terms of the overall uncertainty calculation for the safety I&C system channel. In addition, the SRSS is used to combine the temperature effect, as indicated in the nuclear industry standard [3]. Therefore, the uncertainty calculation method should be improved to get rid of inconsistency because the impact on the safety function does not exist based on the compliance with the unclear regulation and industry standards.

This paper proposes a new method to calculate the PPS cabinet uncertainty so that the uncertainty calculation method maintains consistency. The method proposed has been applied to the Advanced Power Reactor 1400 (APR1400).

2. Methods and Results

Due to the change of the uncertainty combination method for the PPS, the sensitivity analysis is required to quantitatively verify the influence on the safety function. The flowchart of the sensitivity analysis is depicted in Fig. 1.

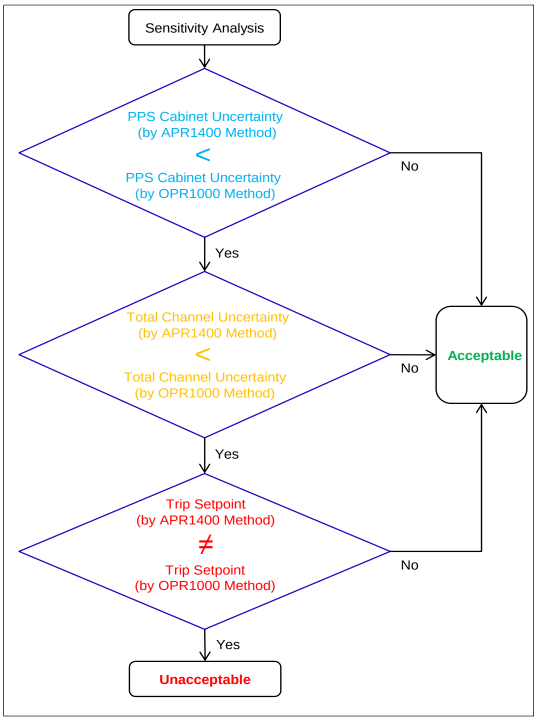

Fig. 1. Flowchart of Sensitivity Analysis

Firstly, the PPS cabinet uncertainty should be evaluated using both combination methods. If two calculation results are the same with each other, it is evaluated that the change does not affect the safety function. Secondly, if the results of the first step are different, the total channel uncertainty should be evaluated combining the PPS cabinet uncertainty with the measurement channel uncertainty. If two total channel uncertainty results are identical, it is evaluated that the change does not affect the safety function. Lastly, if the results of the second step are not equivalent, the trip setpoint should be evaluated considering the total channel uncertainty. If there is no difference between both trip setpoints, it is concluded that the safety function is not affected by the change of the uncertainty calculation method. However, it is not appropriate in terms of safety if the trip setpoint evaluated by APR1000 method is greater or less than the corresponding value by OPR1000 method.

2.1. Uncertainty Calculation Method

The PPS cabinet uncertainty (PPSCU) and measurement channel uncertainty (MCU) for the OPR1000 are given by (1) and (2), respectively.

$$PPSCU_{OPR1000} = (R_S^2 + R_D^2)^{1/2} + B_{TE} \quad (1)$$
$$MCU_{OPR1000} = (RT^2 + RS^2)^{1/2} + B \quad (2)$$

Where:
R_S = Static Random Uncertainty
R_D = Drift Random Uncertainty
B_{TE} = Temperature Effect Bias Uncertainty
RT = Transmitter Random Uncertainty
RS = Signal Processing Device Random Uncertainty
B = Bias Uncertainty

The total channel uncertainty of the safety I&C system channel for the OPR1000 is given by (3).

$$TCU_{OPR1000} = (PPSCU_{OPR1000}^2 + MCU_{OPR1000}^2)^{1/2} + B_{TE} + B \quad (3)$$

The PPSCU and MCU for APR1400 are given by (4) and (5), respectively.

$$PPSCU_{APR1400} = (R_S^2 + R_D^2 + R_T^2)^{1/2} \quad (4)$$
$$MCU_{APR1400} = (RT^2 + RS^2)^{1/2} + B \quad (5)$$

The TCU of the safety I&C system channel for APR1400 is given by (6).

$$TCU_{APR1400} = (PPSCU_{APR1400}^2 + MCU_{APR1400}^2)^{1/2} + B \quad (6)$$

2.2. Uncertainty Evaluation

Regarding the high pressurizer pressure trip parameter for the APR1400, the uncertainty calculation results using two calculation methods are compared to perform the sensitivity analysis.

The PPSCU, MCU, and TCU of the high pressurizer pressure trip parameter for the APR1400 are calculated using the equations (1), (2), and (3), accordingly. The calculation results are shown in Table I.

For the same parameter, the PPSCU, MCU, and TCU are calculated by the equations (4) thru (6), accordingly. The calculation results are shown in Table II.

Table I: Calculation Results Using OPR1000 method

Uncertainty	Values (kg/cm^2)
PPSCU	+/- 0.038 +/- 0.168 (+/- 0.206)
MCU	+/- 4.745 + 0.21
TCU	+/- 4.958

Table II: Calculation Results Using APR1400 method

Uncertainty	Values (kg/cm^2)
PPSCU	+/- 0.172
MCU	+/- 4.745 + 0.21
TCU	+/- 4.958

2.3. Sensitivity Analysis

As shown in Table I, the PPSCU of 0.206 kg/cm^2 is calculated summing the random uncertainty of 0.038 kg/cm^2 and the bias uncertainty of 0.168 kg/cm^2. Since the PPSCU calculated using the OPR1000 method is greater than the PPSCU of 0.172 kg/cm^2 in Table II, there is a possibility of affecting the trip setpoint. So, it is necessary to evaluate the impact on the total channel uncertainty in the first place.

Tables I and II indicate that the TCUs calculated by the OPR1000 and APR1400 methods are exactly the same. Therefore, it is evaluated that the proposed method is appropriate to maintain consistency in calculating uncertainties for the safety I&C system channel.

3. Conclusions

The new uncertainty calculation method for the PPS cabinet has been applied to the APR1400. It is concluded that the new method to combine the temperature effect caused by the PPS cabinet is reasonable since the result of the sensitivity evaluation shows that there is no influence on the total channel uncertainty in spite of the change of the PPS cabinet uncertainty. It is expected that the method proposed will be applied to the future nuclear power plants based on the APR1400.

REFERENCES

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