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WESTINGHOUSE SETPOINT METHODOLOGY FOR CONTROL AND PROTECTION SYSTEMS

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ABSTRACT

Westinghouse has developed an approach for determining channel instrumentation uncertainties which uses the square root of the sum of the squares, with proper accounting for statistically dependent parameters. This paper develops the equation and discusses the independence of the various parameters. It also provides a method of restructuring the plant's Technical Specifications.

INTRODUCTION

In the early 1970's, Westinghouse utilized the method of arithmetic summation for the determination of the uncertainties for a Reactor Trip or Engineered Safety Features Actuation System protection function. This methodology was adequate at that time because the uncertainties and allowances used were relatively easy to cover and still allow more than adequate room for operating margin and flexibility. However, in the 1977/78 time frame, with increased awareness on the part of both Westinghouse and the NRC that additional uncertainties and allowances should be included, Westinghouse initiated a program to re-evaluate the traditional approach and reflect the new or increased parameter values. As a result of this program, the methodology used to combine the uncertainties was revised to the square root of the sum of the squares approach with appropriate treatment of statistically dependent parameters.

METHODOLOGY

Definitions

The parameters considered in this approach are paraphrased below:

PROCESS MEASUREMENT ACCURACY (PMA) - allowance for non-instrument related effects which have a direct bearing on the accuracy of an instrument channel's reading, e.g., temperature stratification in a large diameter pipe.

PRIMARY ELEMENT ACCURACY (PEA) - error due to the use of a metering device, e.g., elbow, orifice, or venturi.

SENSOR CALIBRATION ACCURACY (SCA) - the reference (calibration) accuracy for a sensor or transmitter as defined by SAMA Standard PMC 20.1-1973 [1].

SENSOR PRESSURE EFFECTS (SPE) - the change in input-output relationship due to a change in the static head pressure from the calibration conditions (if calibration is performed at line pressure) or the accuracy to which a correction factor is introduced for the difference between calibration and operating conditions for a d/p transmitter.

SENSOR TEMPERATURE EFFECTS (STE) - the change in input-output relationship due to a change in the ambient temperature (for expected normal operating conditions) from the reference calibration conditions about a transmitter.

SENSOR DRIFT (SD) - the change in input-output relationship over a period of time at reference conditions.

ENVIRONMENTAL ALLOWANCE (EA) - the change in sensor/transmitter output due to adverse radiation and temperature effects from a limiting accident condition. Typically this value is determined from a conservative set of enveloping conditions.

RACK CALIBRATION ACCURACY (RCA) - the reference (calibration) accuracy, as defined by SAMA Standard PMC 20.1-1973 [1], for the process rack modules (cards) in an instrument loop. It is assumed that while each module or card is individually calibrated to a specific tolerance, that all rack modules are string calibrated to within an overall tolerance value.

RACK COMPARATOR SETTING ACCURACY (RCSA) - the reference (calibration) accuracy, as defined by SAMA Standard PMC 20.1-1973 [1], of the instrument loop comparator (bistable).

RACK TEMPERATURE EFFECTS (RTE) - change in input-output relationship for the process rack module string due to a change in the ambient temperature from the reference calibration conditions.

RACK DRIFT (RD) - the change in input-output relationship over a period of time at reference conditions.

The above parameter definitions are applicable for all Westinghouse supplied equipment (Foxboro, Barton and Veritrak/Tobar transmitters, and Foxboro, Hagan 7100 and Westinghouse 7300 process racks). Some slight modifications are necessary to the determination of the transmitter values for Rosemount transmitters, since their specifications are somewhat different than the other three, but the overall errors are essentially the same.

Sensor/Transmitter Allowances

As noted from the definitions, Westinghouse uses five parameters directly related to a transmitter. SCA, SPE, STE and SD will be discussed in this section and EA will be discussed later. Two of these parameters are considered to be independent (SPE and STE) and two are conservatively considered to be dependent (SCA and SD). The SPE and STE terms are independent because they are deviations of two separate effects from two different unrelated reference conditions. The magnitudes of these two terms are based on Westinghouse and vendor equipment specifications. The SCA and SD terms are conservatively noted as being dependent because at the time the methodology was developed, very few plants were recording "as left/as found" data to assist in the determination of drift. In the mid 70's many plants using Westinghouse protection systems simply recorded the fact that the calibration was within specification and not the actual "as left" value. When periodic surveillance was later performed, the only determination possible was the deviation from the nominal setpoint and not the actual deviation from the "as left" point. Westinghouse then determined that the assumption that these two parameters were interactive, or dependent, would conservatively bound the

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actual uncertainties of calibration plus drift for a given transmitter. The magnitude of SCA is based on the combination of the vendor's equipment specification for the reference accuracy and the plant's calibration procedure for deviation from the nominal calibration value. The value for SD is based on the vendor's equipment specification and Westinghouse review of drift data.

If a plant recorded "as left/as found" data during calibration and periodic surveillance it would be quite reasonable to treat SCA and SD as independent variables. With the generation of a sufficiently large data base, a more accurate, statistically based determination of the SCA and SD terms would be possible. In the authors' opinion this would result in an approximate 5% reduction in the overall uncertainty for an instrument loop and would also result in a better determination of the adequacy of a transmitter's operation. The recording and utilization of the "as left/as found" data is strongly recommended by Westinghouse and is consistent with the recommendations of ISA Standard S67.04, 1982 [2].

The Westinghouse reference to SAMA Standard PMC 20.1-1973 [1] in regards to SCA (and RCA and RCSA) has quite an impact on both the plant and the calculated uncertainty for the various protection functions. The SAMA standard notes that when calibrating an instrument (transmitter or rack module) the accuracy of the calibration equipment must be taken into account if the uncertainty of the calibration or test equipment is greater than 10% of the calibration value, e.g., if the calibration tolerance is ± 0.5%, then the accuracy of the calibration or test equipment must be less than ± 0.05% if it is to be ignored.[3] If this accuracy is not met, then the actual accuracy of the calibration equipment should be included as part of the SCA, RCA, or RCSA value. This is in contrast with IEEE Standard 498-1980, which notes that the accuracy of the calibration equipment should be less than ± 25% of the calibration tolerance.[4] Westinghouse has determined that ignoring the calibration equipment accuracy has little or no impact on the Westinghouse methodology if the SAMA standard is met, however, this is not necessarily true if the IEEE standard is met and the calibration equipment uncertainty is ≥ 15% of the calibration tolerance. The end result of this effect is that the plant must either purchase very accurate calibration and test equipment or lose some degree of operating margin.

Rack Allowances

From the definitions it can be seen that Westinghouse uses four parameters for the process rack uncertainties, RCA, RCSA, RTE and RD. In the Westinghouse approach, RCA, RCSA and RD are conservatively noted to be dependent parameters and RTE is considered to be independent. For much of the same reasons as for the transmitters, Westinghouse assumes that the rack calibration and drift terms are dependent. The inclusion of the RCSA term is a specific allowance for the plants that calibrate the trip bistable separately from the remainder of the racks. This is not exactly consistent with the string calibration assumption noted in the definition but it is an acceptable procedure within the methodology. The magnitude of the RTE term is based on Westinghouse qualification test data for the racks. The RCA and RCSA values are based on the combination of the equipment's reference accuracy and the plant's procedure for allowable deviation from the nominal calibration value. The value for RD is based on equipment specifications and the results of a Westinghouse review of rack drift data.

If a plant performed a string calibration of the instrument loop, including the bistable, and recorded the "as left" data for the string, it would be possible to reduce the number of terms in the methodology to RCA and RD. Utilization of the "as left" data to confirm that the RCA term was satisfied and "as found" data to determine the RD term, it would be possible to remove the conservative assumption that the two terms were interactive and calculate the loop uncertainty based on the assumption that they were statistically independent. In the authors' opinion this would result in an approximate 25% reduction in the total loop error.

Other Allowances

The three remaining allowances to be discussed are PMA, PEA and EA. As noted in the definitions, PMA is an allowance for non-instrument related effects. These encompass a large number of different uncertainties which have applicability to some, but not all, of the Westinghouse protection functions. Examples of the PMA terms used are: temperature stratification in large diameter piping for measurements with RTDs, the impact of a change in Tavg (which impacts the water density and thus the neutron leakage current) in the downcomer region of the reactor vessel in front of neutron detectors, the impact of the accuracy of the rod control system (Tavg) on the density of the primary coolant in the cold leg elbow where d/p transmitters are used to infer flow rate, the accuracy of a precision flow calorimetric used to normalize the cold leg elbow tap d/p transmitters, and the impact of the accuracy of the Pressurizer pressure control system (which impacts the density of the water) on the Pressurizer level transmitter. Some of these values involve detailed calculations with multiple uncertainty groupings which are reduced to a single value. Other values are simply allowances which are known to be conservative and bounding.

PEA is an allowance for use of a metering device for the measurement of flow. This term is used by Westinghouse for elbows and venturis, but would also be used for an orifice if one were used in a protection function. When an elbow is used for a protection function, the d/p transmitter used to make the measurement is normalized to a precision flow measurement to reduce the uncertainty for the flow coefficient for the elbow. The PEA term is then an allowance for the noisy signal that is characteristic of use of an elbow. When a venturi is used, this term is the accuracy of the determination of the flow coefficient for that device. This is usually performed at an independent laboratory to a high confidence level.

The EA term accounts for the impact of the high temperatures and radiation exposure due to a limiting accident in the vicinity of the transmitter. For Reactor Trips and ESF function actuation, the primary contributor is the high temperature that may be experienced at the beginning of a Main Steamline Break, a Main Feedwater Pipe Break, or a Loss of Coolant Accident. The second principal contributor is the effect of high radiation exposure from a Loss of Coolant Accident. These two contributors are arithmetically summed to conservatively bound the total impact of the event. Because of the methods in which the transmitters are specified and environmentally qualified, Westinghouse treats EA as if it were a bias term. As a result of recent testing of more than 50 transmitters performed by one of the principle suppliers to Westinghouse, it was determined that the historical value used for EA for those transmitters was non-conservative by as much as 40%. This demonstrates the need for a comprehensive

qualification test program that involves more than just three or four samples to represent a large population if one expects to determine the magnitude and areas of random variation of an uncertainty with a high confidence level. As a result of the same testing program, it may be possible to determine random and bias components of the temperature contribution. However, more testing is necessary before it is possible to utilize this approach on all Westinghouse supplied transmitters. As can be seen, Westinghouse exercises great effort to determine uncertainties in a conservative manner (usually by setting upper bound values) to establish high confidence limits.

Uncertainty Combination

As noted in the previous sections, the Total Channel Allowance (TCA) is the square root of the sum of the squares after forming statistically independent groups. From the above discussion it has been noted where Westinghouse makes conservative assumptions concerning the treatment of the various parameters. The resulting equation is as follows:

$$TCA_1 = [(PMA)^2+(PEA)^2+(SCA+SD)^2+(SPE)^2+(STE)^2+(RCA+RCSA+RD)^2+(RTE)^2]^{1/2} + EA. \quad (1)$$

If the plant recorded "as left/as found" data and utilized it in the determination of drift and performed a string calibration on the racks that included the bistable, then Equation 1 could be revised to as follows:

$$TCA_2 = [(PMA)^2+(PEA)^2+(SCA)^2+(SPE)^2+(STE)^2+(SD)^2+(RCA)^2+(RTE)^2+(RD)^2]^{1/2} + EA. \quad (2)$$

The Total Channel Allowance is then compared with the Total Allowance (TA) which is the difference between the Nominal Trip Setpoint (in the plant's Technical Specifications) and the Safety Analysis Limit (the value for the trip setpoint used in the Safety Analysis). Obviously TCA must be less than or equal to TA if the Safety Analysis assumption concerning the trip setpoint is to be satisfied.

TECHNICAL SPECIFICATIONS

Westinghouse uses the components of Equation 1 to determine an Allowable Value and a Maximum Value for use in the plant's Technical Specifications and surveillance procedures. The Allowable Value is the value to which the process racks and bistable may drift before specific action must be taken by the plant I&C staff. As part of the overall approach, Westinghouse has determined that the Allowable Value may be one of several calculated values, which ever is the most limiting. The first value (T1) is simply the arithmetic sum of the rack calibration and drift values,

$$T1 = RCA + RCSA + RD. \quad (3)$$

The second value is based on the assumption that the transmitter drifts in a random fashion for both magnitude and direction and that parameters not checked are also randomly distributed with normal or near normal probability distributions. This calculation is conservatively approximated by,

$$T2 = TA - [(PMA)^2+(PEA)^2+(SCA+SD)^2+(SPE)^2+(STE)^2+(RTE)^2]^{1/2} - EA \quad (4)$$

For protection functions that have more than one input to the bistable, the NRC has determined that either T2 or T3 should be used for the Allowable Value, where:

$$T3 = [(RCA_1+RCSA_1+RD_1)^2+(RCA_2+RCSA_2+RD_2)^2]^{1/2} \quad (5)$$

and the subscripts indicate input channel 1 or 2. The Allowable Value is then the Nominal Trip Setpoint plus the most limiting of the T values (T1 or T2 for single input functions and T2 or T3 for multiple input functions). When the process racks plus bistable have drifted past the Allowable Value then the I&C staff has three options: (1) check the transmitter for the channel to determine if it has drifted in a manner that would compensate for the rack drift, (2) determine if the function has sufficient margin to accept the magnitude of the drift, and (3) do nothing to determine margin, just recalibrate the rack and note the deviation for the plant's reports.

Westinghouse calculates the Maximum Value to be used in the plant's surveillance procedures to assist the I&C staff in the determination of whether there is sufficient margin in the function (TA >> TCA) to accept the rack drift. The calculation for the Maximum Value assumes that the transmitter has drifted to it's worst condition allowed in Equation 1, i.e., the transmitter drift is SCA + SD and in the non-conservative direction. The equation for this value is:

$$T_{max} = TA - [(PMA)^2+(PEA)^2(SPE)^2+(STE)^2+(RTE)^2]^{1/2} - (SCA+SD) - EA. \quad (6)$$

If the bistable's trip setpoint is greater than Tmax, then the I&C staff must either check the transmitter for compensating drift or simply determine that the channel is out of specification and recalibrate. Engineering prudence indicates that any time the channel is found to be outside of the Nominal Trip Setpoint plus RCA + RCSA, the channel should be adjusted to within the calibration tolerance.

CONCLUSIONS

In the determination of instrument channel uncertainties, Westinghouse attempts to include all known and reasonable errors and allowances. The method used to combine the uncertainties is the conservative approach of the square root of the sum of the squares after accounting for statistically dependent effects. The methodology makes several conservative assumptions with regards to the determination of dependency between several sensor/transmitter or rack parameters. The importance of proper calibration techniques and use of accurate calibration equipment was explained and the effects of the use of either the SAMA or IEEE standard for the determination of acceptable calibration equipment accuracy was noted. The equation developed to calculate the instrument uncertainty leads to several subsets that may be used to calculate the allowed rack deviation determined during periodic surveillance which is usually larger than the rack drift value alone. This methodology has been in use since June, 1978 with explicit NRC approval (with regard to the calculation of Allowable Values for use in the plant specific Technical Specifications) since August, 1982.[5]

REFERENCES

[1] Scientific Apparatus Makers Association, Standard PMC 20.1-1973, "Process Measurement and Control Terminology," page 4.

[2] Instrument Society of America, Standard S67.04, 1982, "Setpoints for Nuclear Safety-Related Instrumentation Used in Nuclear Power Plants," page 12.

[3] Scientific Apparatus Makers Association, Standard PMC 20.1-1973, "Process Measurement and Control Terminology," page 36.

[4] Institute of Electrical and Electronic Engineers, Standard 498-1980, "IEEE Standard Requirements for the Calibration and Control of Measuring and Test Equipment Used in the Construction and Maintenance of Nuclear Power Generating Stations," page 6.

[5] NUREG-0717 Supplement No. 4, "Safety Evaluation Report Related to the Operation of Virgil C. Summer Nuclear Station, Unit No. 1, Docket No. 50-395," pp. 7-1 - 7-3.