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Study on virtual redundancy among process parameters for accident management applications

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1. Introduction

After the Fukushima accident, nuclear industry has launched quite exhaustive research projects to address safety challenges in in Beyond Design Basis Accident (BDBA). It has been suggested that the Severe Accident Management Guidelines (SAMG) could only be useful if the monitoring of critical parameters is somehow made available to the operator, even in SBO condition [1]. The research at this point can be divided into three streams, 1) focused on the development of self-powered sensors and instrumentation, 2) developing intelligent systems that can diagnose and accident type and 3) developing indirect ways that is, methods to assess the safety critical parameters from other statistically related parameters. This first approach is quite expensive, second approach suffers from the limitation that infinite number of accident scenarios cannot be simulated. However, the only way to access the parameters during severe accidents is through simulation codes. Even-though, the process parameters data contain uncertainty, this is the only thing to start with severe accident management.

International Nuclear Energy Research Initiative (INERI) project has started research to address various aspects of safety management during severe accidents. As a part of INERI team, we are investigating correlations among process parameters in such a way that safety critical information could be secured by means of other non-safety or virtual parameters during a severe accident. This is known as virtual redundancy of information. This will improve the availability of information in case one channel for information is lost.

In this paper, we will discuss methodology, preliminary results and directions for further study.

2. Materials and Methods

Thousands of sensors are installed at a nuclear power plant to measure parameters that ensure its performance and safety condition. However, a smaller set of parameters is vital for power plant's safety management. US NRC has provided a SAMG on preferred process parameters be monitored during and following an accident [3]. After Fukushima accident, utilities are even more interested in methods to secure safety-critical information. We hypothesized a network of sensors to be developed on statistical correlations which could secure the safety critical information (SAMG based parameters) from non-safety or virtual measures. Such a network is shown in figure 1. The connecting lines physically mean the statistical correlation.

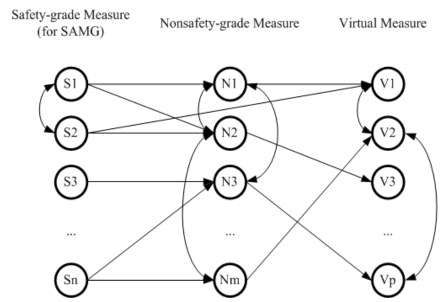

Figure 1: Robust network of sensors for SAM application.

The complete stages for developing SAMG parameters' correlation with other process parameters are shown in figure 2. Post-accident monitoring data generated from simulations is selected and corrected for SAMG and other important parameters for each accident scenario. This preprocessing step may include scaling, filtering, reduction etc. adjustments. Preprocessing is followed by computation of statistical correlation, grouping and selection on the basis of numerical bounds and safety importance respectively for the construction of robust sensing network. All these steps have been implemented in MATLAB where, a user defined number of parameters can be collected for each SAMG parameter on the basis of numerical bounds set for parametric matching.

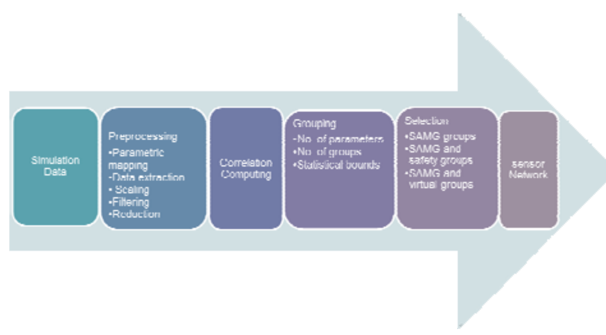

Figure 2: Steps for the development of robust sensing network.

2.1 *Simulation Data*

In order to establish correlations among the process parameters, firstly we utilized RISARD system to extract data for severe accident scenarios, that had been collected for initiating events (1) large loss of coolant accident (Large

LOCA), (2) medium loss of coolant accident (Medium LOCA), (3) small loss of coolant accident (Small LOCA), (4) station blackout accident (SBO), (5) loss of off-site power accident (LOOP), (6) steam generator tube rupture accident, and (7) loss of feed-water accident. The database contains a total of 70 accident scenarios analyzed on the basis of probabilistic safety analysis of the Ulchin 3, 4 plants. RISARD system generates thermal hydraulic and source term data for 840 parameters for MAAP nodalization model for 72 hours [2, 4].

2.2 Preprocessing

There were two main problems with the MAAP data, 1) all parameters are not the physically measurable quantities. We performed a mapping between process instrumentation, SAMG based parameters, and MAAP parameters. Among the recognized SAMG based parameters were, pressure in pressurizer, pressure in primary system, core exit temperature, water level in RWST, surface temperature of hot leg pipes etc. Parameters having no match with any of the reactor instrumentation will be regarded as virtual measures. The second problem was the inhomogeneity in time scale, which was present throughout the data.

2.3 Correlation and Grouping

We developed a computer program to perform time scale homogenization and to compute statistical correlation defined by correlation coefficient. Equation 1 defines the simple correlation for two variables x and y.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y} \qquad (1)$$

Correlation is the most widely used statistical measure and is being used in process industry as a basis for grouping variables for online monitoring applications [5].

2.4 Group Selection

An algorithm was implemented to extract groups having SAMG based parameter as principle variable. And also the data regarding these parameters were stored for verification.

3. Simulation and Results

Several accidents provided from the MAAP data were processed through the steps shown in figure 2 to realize the possibility of virtual redundancy of information. Figure 3 shows variation of ten variables that have high correlation with pressurizer temperature for LOCA (left) and SGTR (right) accidents. In these cases, there were no similar candidates except the SAMG parameter. However, the variation patterns were distinct. Similarly, figure 4 shows the behavior of parameters having similarity with parameter 'temperature of hot leg pipe'. Here, besides visual distinction in patterns, a similarity between group parameters was also observed.

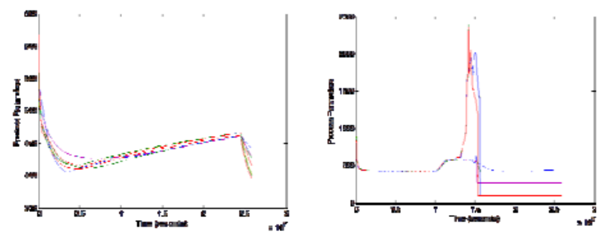

Figure 3: Variation of group based on pressurizer temperature.

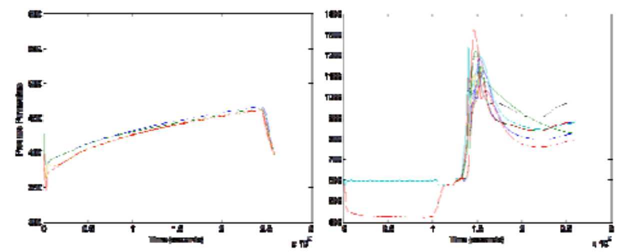

Figure 4: Variation of group based on temperature of hot leg pipes.

4. Conclusions

We found that several process parameters exhibit distinct variation pattern for a particular accident and several other parameters can also have the similar trends which strengthens the possibility of having virtual redundancy of information. It was also found that the group sets are not unique for different accidents. Also, there are several issues regarding simulation data, physical parameters and grouping need to be explored. It is therefore recommended that a comprehensive study covering full set of available scenarios should be performed.

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