CONF-840614--44

CONF-840614--44

DE84 005538

This summary is of technical quality
and accuracy that reflects credit on
the RAS Division

A Methodology for Validation of Safety Parameters and Fault Detection and Isolation*

Constantine P. Tzanos

Reactor Analysis and Safety Division
Argonne National Laboratory
Argonne, Illinois 60439

The submitted manuscript has been authored by a contractor of the U. S. Government under contract No. W-31-109-ENG-38. Accordingly, the U. S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U. S. Government purposes.

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE.

It has been reproduced from the best available copy to permit the broadest possible availability.

---

*Work performed under the auspices of the U. S. Department of Energy.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

A Methodology for Validation of Safety Parameters and Fault Detection and Isolation

The reliability of plant control and protection is strongly dependent on the reliability of the plant instrumentation system. The experience from the operation of nuclear power plants has shown that erroneous and contradictory instrument signals confuse the operator and delay corrective action. The same experience has also shown that about 10% of the total unplanned shutdowns are due to instrument failures. Plant safety as well as plant availability can be enchanced by improving the reliability of instrument information.

In this paper a methodology for instrument data validation as well as fault detection and isolation, based on analytic redundancy, is presented. This work differs from previously reported work on analytic redundancy in that validation of all the main parameters of the plant heat transport loops is sought by using plant-wide instrument information. An LMFBR plant is used as a reference, and validation of the following plant parameters is considered: reactor power (Q), reactor inlet (T_{IC}) and reactor outlet (T_{OC}) coolant temperatures, intermediate heat exchanger (IHX) inlet (T_{IS}) and outlet (T_{OS}) secondary coolant temperatures, steam generator feedwater temperature (T_w), steam temperature (T_s) and pressure (P_s), as well as primary (G_p), intermediate (G_I), and feedwater (G_w) flow. In this paper, only validation at steady state conditions will be discussed.

Data validation and fault detection models that utilize the concept of analytic redundancy are based on the comparison of redundant direct (sensor) and analytic measurements [1,2]. Analytic measurements are generated by the analytic models that describe the different plant operation processes.

Validation of the primary, intermediate, and feedwater flow is first sought by using local instrumentation information as discussed in Ref. 2. More specifically, a given flow value is validated if at least two measurements are consistent. Analytic flow measurements are generated by using the pump similarity, the pump power usage, and pressure drop correlations [2]. If validation of one or more of the flow parameters (G_p, G_I, G_w) fails at this step, its validation is sought in the next step where plant-wide instrument information is used.

All the plant parameters that are considered for validation, can be grouped into a number of sets, such that each of these sets contains a minimum number of parameters that are sufficient to define the system state. Such a set is called "minimum system state definition set." From any minimum system state definition set of measured parameters analytic measurements can be generated for all the remaining measured parameters utilizing the analytic models that describe the system. If it is known that all the measurements contained in the minimum system state definition set are correct, the analytic measurements of the remaining parameters generated by the set can be compared with their direct measurements. If there are direct measurements that are not consistent with their analytic measurements, the sensors that generated these measurements must have failed. Thus, the comparison of analytic and direct measurements provides data validation as well as fault detection and isolation. However, it cannot be assured that all direct measurements contained in a minimum system state definition set are correct if at least one of the analytic measurements, generated by this set, is not consistent with its direct (sensor) measurement. Therefore, to validate all the system parameters, at least one consistent "minimum system validation set" must exist. A minimum system validation set is defined as a set that consists of one minimum system state definition set plus one more parameter whose value can be analytically generated from the minimum system state definition set.

Although for validation of all system parameters the existence of a consistent minimum system validation set is a necessary condition, this condition is not always sufficient. If all the sensors of a minimum data validation set are stuck at consistent indications, or some of them have failed such that still consistent indications are obtained, these failures cannot be identified and any conclusions of validation will be erroneous. However, since the probability for the occurrence of such an event in a large number of sensors measuring different plant parameters at different parts of the plant is extremely small, this condition is considered also sufficient. The assumption that this condition is necessary as well as sufficient, is the basis of the methodology discussed in this paper for validation of plant-wide parameters. However, if it is desired, additional checks can be imposed to strengthen the sufficiency of this condition.

Based on the above discussion, the problem of data validation and fault detection using plant-wide parameters is reduced to a search for a consistent minimum system validation set. To simplify the algorithm of this search, and reduce the required computational effort, the following observations are made.

First, to validate all the system parameters considered, no more than four failed sensor sets can be tolerated (each set measures the same parameter). This is the case, because eleven plant-wide parameters have been considered for validation, and seven of them are needed to form a minimum system validation set. Thus, the algorithm terminates its search, if the conclusion has been reached that validation has failed because more than four sets of sensors must have failed. However, the above limitation of four sets of sensors does not take into account the failures that can be tolerated in the validation of flows using local system parameters as discussed earlier. If these failures are taken into account, it can be shown that up to 12 failed sensor sets can be tolerated.

Second, to validate all the system parameters considered, no more than one failed sensor set can be tolerated from those measuring the water-side steam generator parameters. To define the state of the steam generator, five parameters from the set (G_I, T_{IS}, T_{OS}, G_w, T_w, P_s, T_s) are needed. Consequently, a minimum steam generator validation set contains six of these parameters (out of seven). Thus, even if all the sodium-side parameters (G_I, T_{IS}, T_{OS}) are validated, only one failed set of sensors can be tolerated from those measuring the water-side parameters.

To make the search for a minimum system validation set computationally efficient, this search starts by generating analytic power measurements utilizing the primary, intermediate, and water loop parameters. These analytic measurements and the direct power measurements (from neutron flux measurements) are compared for consistency. If all of them are consistent, all the measurements used for their generation are valid, and the search proceeds to the next validation time interval. If all of them are not consistent, there are three possible cases: three are consistent, two are consistent, all are inconsistent. The search proceeds by examining only the possible minimum validation sets that arise from one of these three cases. Failure to find a minimum validation set means that either there are more failed sensor sets than required for validation, or the system is under a transient. Then, the search proceeds with analyses using transient system models which are out of the scope of this paper. Finally, to minimize computation time, analyses with the core, IHX, and steam generator models will be performed in parallel and the algorithms used in these models are tailored to the purposes of a data validation scheme.

References

1. C. H. Meijer et al., "On-Line Power Plant Signal Validation Technique Utilizing Parity-Space Representation and Analytic Redundancy," EPRI NP-2110, Electric Power Research Institute (1981).

2. O. L. Deutsch et al., "Development and Testing of a Real-Time Measurement Validation Program for Sodium Flowrate in the EBR-II," CSDL-R-1592, The Charles Stark Draper Laboratory, Inc. (1982).