Trans. Am. Nuc. Soc., Vol. 44, August 1983

asymmetries suggested by Table I had persisted. Without the changeover to Gamma-TIPs, a 2 to 3% derate would have hampered operation for eight weeks.

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6. Signal Validation for a Boiling Water Reactor Suppression Pool, *J. Fisher, A. Ray, R. Ornedo (Draper Lab), Ed Kujawski (NUTECH), S. M. Divakaruni (EPRI), Phil Smith (GPU Nuclear)*

INTRODUCTION

A real-time signal validation program has been developed for monitoring a boiling water reactor (BWR) suppression pool and related sensors. The major objectives are to (a) improve the reliability of information that is needed to implement emergency operating procedures, (b) provide a reliable, cost-effective means for suppression pool temperature monitoring,[1] and (c) validate data for an SPDS.[2-4] The methodology can also be used to determine the additional sensors necessary to meet the aforementioned goals. The program has been tested with Oyster Creek plant simulation data. A variety of sensor and plant component faults were successfully identified during simulated steady-state and transient operations.

METHODOLOGY

There are three basic elements of the methodology that have been developed for aerospace and nuclear industries: parity space representation, analytic redundancy, and the signal validation architecture. The parity space algorithm[5-7] makes use of consistency tests among all measurements of a given variable for fault detection and isolation (FDI). An estimate of the variable is obtained as a weighted average of the consistent measurements. Consistency is defined relative to an acceptable error magnitude for each measurement. The methodology does not require detailed knowledge of sensor and plant noise statistics. This test is embodied in the decision/estimator (D/E) code unit. Analytic redundancy refers to the measurement of a variable using the physical relationships among other variables. A low-order and often nonlinear model of these relationships is used to generate a measurement of a variable that may then be compared to available direct (sensor) measurements for detection of both sensor and plant component failures. The signal validation architecture, as represented in Fig. 1, combines the FDI logic units and analytic measurement calculators to obtain reliable estimates and fault resolution, and to recognize common-cause failures.

OBJECTIVES

The operating objectives are to:

1. Validate the sensor signals for suppression pool temperature, level, and pressure.
2. Use analytical redundancy to provide suppression pool bulk temperature.
3. Determine the status of safety/relief valve (SRV) positions.

The conditions under which the system should be fully operational include normal power operation and transients that (a) have a reasonable probability of occurring during the plant lifetime, and (b) require monitoring of suppression pool parameters as a basis for operator actions. Typical examples are stuck-open SRVs, inadvertently opened SRVs, and turbine trip without bypass. An additional program objective is to aid in the definition of the minimum set of suppression pool temperature sensors necessary. The program is set up to run with a maximum of 20 temperature sensors; any subset of these may be turned off to evaluate the accuracy with a reduced set. This feature can also be useful in estimating system accuracy in the presence of sensor failures.

MODELS FOR ANALYTIC MEASUREMENTS

Referring to Fig. 1, ZVRT provides an analytic measurement of SRV position, based on a rise of a quencher bay temperature of >10°F. This model cannot distinguish between different SRVs that feed the same quencher. Hence, the analytic measurement value is changed for each SRV that feeds the quencher bay in which the temperature rise is detected. Additional confirming direct measurements are used to determine validated valve position. An analytic measurement of the flow through each SRV, WSRV1, is obtained from dome pressure (PDM) and wetwell pressure (PWW). A second model for relief flow, WSRV2, is determined by the amount of a relatively abrupt change in the steam flow/feed flow mismatch. In general, there will be a slight mismatch because of flow sensor errors and CRD flow, so the mismatch itself cannot be used to generate a relief flow estimate. However, an abrupt change in this mismatch is indicative of an open SRV. Currently, this model is disabled temporarily when RPV level is changing rapidly, because part of the mass imbalance can be temporarily stored in the pressure vessel.

WCSA generates an analytic containment spray flow, based on discrete signals for the status of each pump in the containment spray system.

Two analytic measurements of the bulk temperature, TBLK1A and TBLK1B, are formed by volume-weighted averages of the suppression pool sensor readings. Two other analytic measurements of the bulk temperature, TBLK2 and TBLK3, are formed by modeling conservation of energy for the torus.[8] The energy input is the product of SRV flow rate and (saturated) steam enthalpy. The energy loss is primarily due to the containment spray system, as determined by the system flow rates and discharge temperatures. TBLK2 uses relief valve flow as estimated by WSRV1; TBLK3 uses WSRV2. An additional input is the discrete loss-of-coolant-accident (LOCA) signal. Both models would be inaccurate in the occurrence of a LOCA; hence, on receipt of such a signal, their outputs are marked invalid. TBLK4 is essentially an additional direct measurement of the bulk temperature, provided by the containment spray suction temperature sensor only when at least one containment spray pump is on.

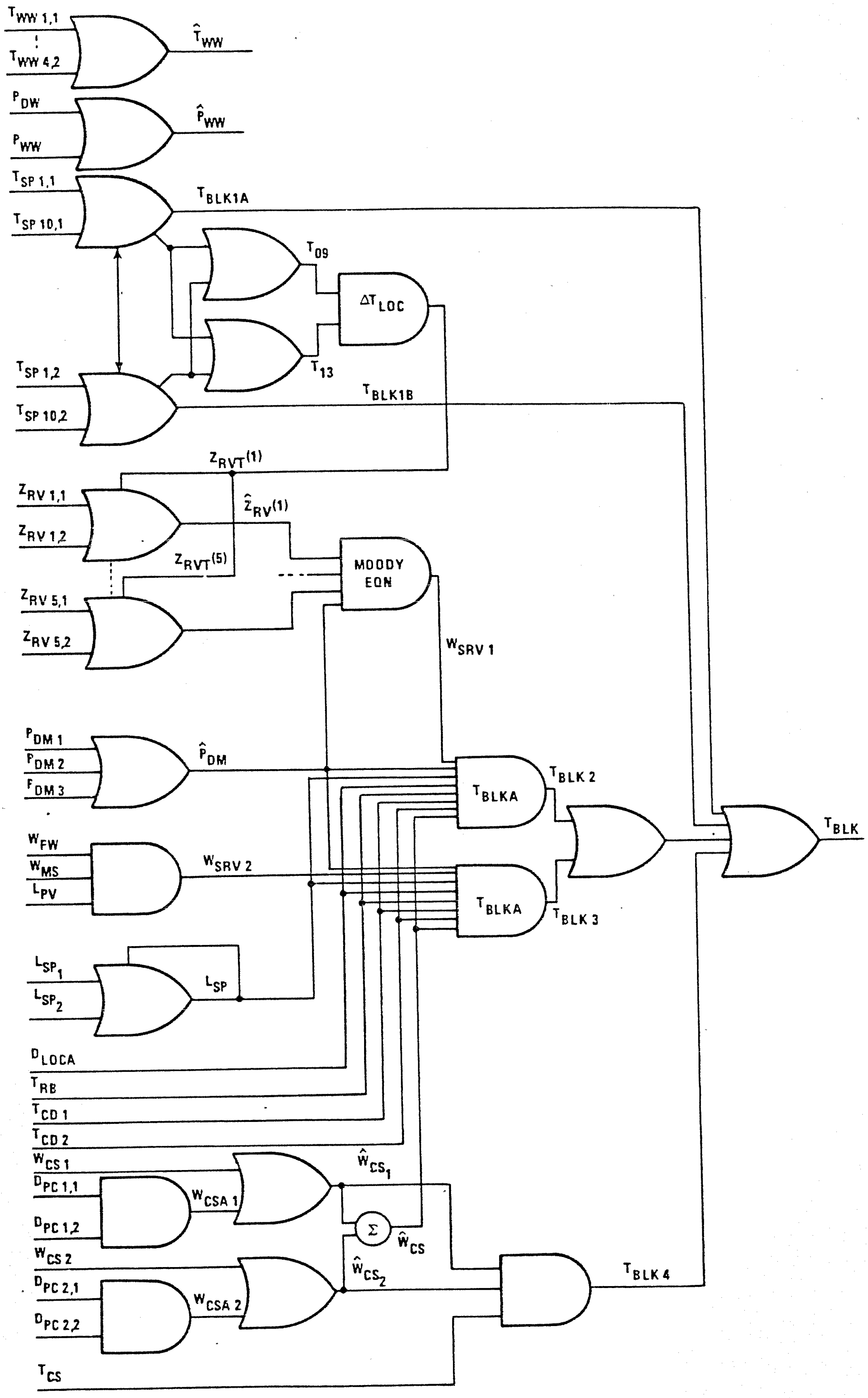

Fig. 1. Signal validation logic flow diagram.

SIGNAL VALIDATION ARCHITECTURE

The signal validation diagram (Fig. 1) defines the flow of information at each sample time. On the left side are the analog and discrete input signals. The OR gate symbols indicate decision estimators; the AND gate symbols represent analytic measurement calculators. A partial exception to this convention is the use of the decision/estimator (D/E) symbol to indicate generation of TBLK1A and TBLK1B. The actual logic for the sensors consists of several D/Es grouped to detect common-cause failures.[8]

Whenever at least triplex sensor redundancy exists, estimates are obtained from the direct measurements. This is the case for wetwell temperature (TWW) and RPV dome pressure (PDM). The dual-redundant wetwell pressure (PWW) and suppression pool level (LSP) measurements are also supplied directly to D/Es. Since these parameters are expected to change slowly, a form of analytic redundancy is effectively supplied by comparison with the previous estimate when a fault is detected.

The two analytic bulk temperature measurements, TBLK2 and TBLK3, are combined by a D/E into one measurement before the final D/E chooses TBULK, to ensure that a common-cause failure of these analytic measurements cannot lead to a wrong decision in their favor by the final D/E.

RESULTS

Test cases are constructed from RETRAN and CONTEMPT code runs[9] and steady-state data. In addition, a semiempirical model was used to generate the temperature distribution in the suppression pool. Transient test cases include (1) stuck-open SRVs at full power, with subsequent suppression pool cooling initiation and scram, for (1a) two CSHXs (containment spray heat exchangers) and (1b) one heat exchanger operating; (2) turbine trip without bypass or isolation condenser operation, with (2a) no CSHXs, (2b) one CSHX, and (2c) two CSHXs operating. With no failures, the validated bulk temperature estimate remained correct to within 3 deg for the length of the transient. The estimate was only slightly degraded in transients with injected sensor failures, including common-mode failure of one suppression pool temperature sensor division.

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