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THE EFFECTS OF PARAMETER VARIATION ON MSET MODELS OF THE CRYSTAL RIVER-3 FEEDWATER FLOW SYSTEM

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INTRODUCTION

In this paper we develop further the results reported in Reference 1 to include a systematic study of the effects of varying MSET models and model parameters for the Crystal River-3 (CR) feedwater flow system. The study used archived CR process computer files from November 1 - December 15, 1993 that were provided by Florida Power Corporation engineers Fairman Bockhorst and Brook Julias. The results support the conclusion that an optimal MSET model, properly trained and deriving its inputs in real-time from no more than 25 of the sensor signals normally provided to a PWR plant process computer, should be able to reliably detect anomalous variations in the feedwater flow venturis of less than 0.1 % and in the absence of a venturi sensor signal should be able to generate a virtual signal that will be within 0.1 % of the correct value of the missing signal.

The importance of accurately determining the feedwater flow rate in nuclear power reactors is well established and has been extensively documented [1-4]. Although several alternative feedflow measurement systems are under development, a venturi meter in each feedwater loop is the feedwater flow determination method that is currently used to derive the reactor power level in all PWRs licensed by the NRC. The occurrence of feedwater venturi meter fouling has also been established [2]. The degree of fouling and the nature of deposits have been found to vary significantly from plant to plant and results in flow measurements of 1 – 2 % higher than the actual flow. The onset of the fouling has been observed to develop early in a reactor operating cycle, after as little as 2 months of operation. Hence during most of the cycle, the feedwater flow meters may produce flow rate measurements higher than actual flow rate, thus yielding artificially higher calculated thermal powers. Overestimation of the feedwater flow rates due to flow meter fouling has been reported to be the single most frequent cause of derating of PWRs[2].

METHODOLOGY

For several years, Argonne National Laboratory (ANL) has had under development a package of statistical modeling programs. The method developed by ANL is called Multivariate State Estimation Technique (MSET) and can be applied to any monitored process. In essence MSET consists of two essential modules. The first module estimates the state of the system by using a nonlinear estimation operator and previously learned states in which the system is assumed to be operating normally. The second module is the fault detection module, which is based on the most sensitive, accurate and practical method available, the Sequential Probability Ratio Test (SPRT). The mathematical basis for each module is described in detail in reference 5.

The methodology followed in this investigation was to select a time interval for MSET model training when all the sensors in the plant were assumed to be operating normally. Then, 280 sensors from the plant secondary and primary systems potentially related to both loop A and loop B venturi meter indications were selected. The sensor readings for the chosen sensors during the training interval were extracted from archived Crystal River-3 process computer data files and concatenated into a matrix format. After sensor re-calibration and electronic malfunction spikes in the extracted data were eliminated, a linear cross correlation analysis of the data with respect to the venturi meter readings from both loops was performed. The sensors were then rearranged in the descending order of the sum of the absolute value of the correlation coefficients and the most highly correlated 25, 50, 75 and 100 sensors were used to define four venturi meter models. For each model, training matrices with 200, 300 and 400 vectors were created and MSET was run for all the models. The average root mean square (rms) deviation between the observed and estimated of the venturi meter signal and the false alarms rates given by the mean SPRT calculation were the criteria used to quantify the model performance.

RESULTS

When the system was operating under normal operating conditions, excellent estimation results (rms between 1 – 4.5 klbm/h for full-power feedwater flow rates at about 5400 klbm/h) were achieved for all the models. The results for the loop B venturi are presented in Figure 1. Similar results, with similar values and identical trends were obtained for the loop A venturi. The results support three important conclusions:

1. All of the models are able to estimate the normal, 100% full power value of either venturi flow meter to within 0.08 %.
2. The optimum model (lowest rms estimation error) is always achieved with the 25 most highly correlated sensors.
3. The optimum 25-sensor model is the one that uses the most training vectors (400 vectors, relative rms estimation error < 0.02 %).

Also, the model fault tolerance was studied under normal operation conditions and the results showed that the SPRT algorithm met the specified criteria (0.1 % false alarm rates) for all the models considered.

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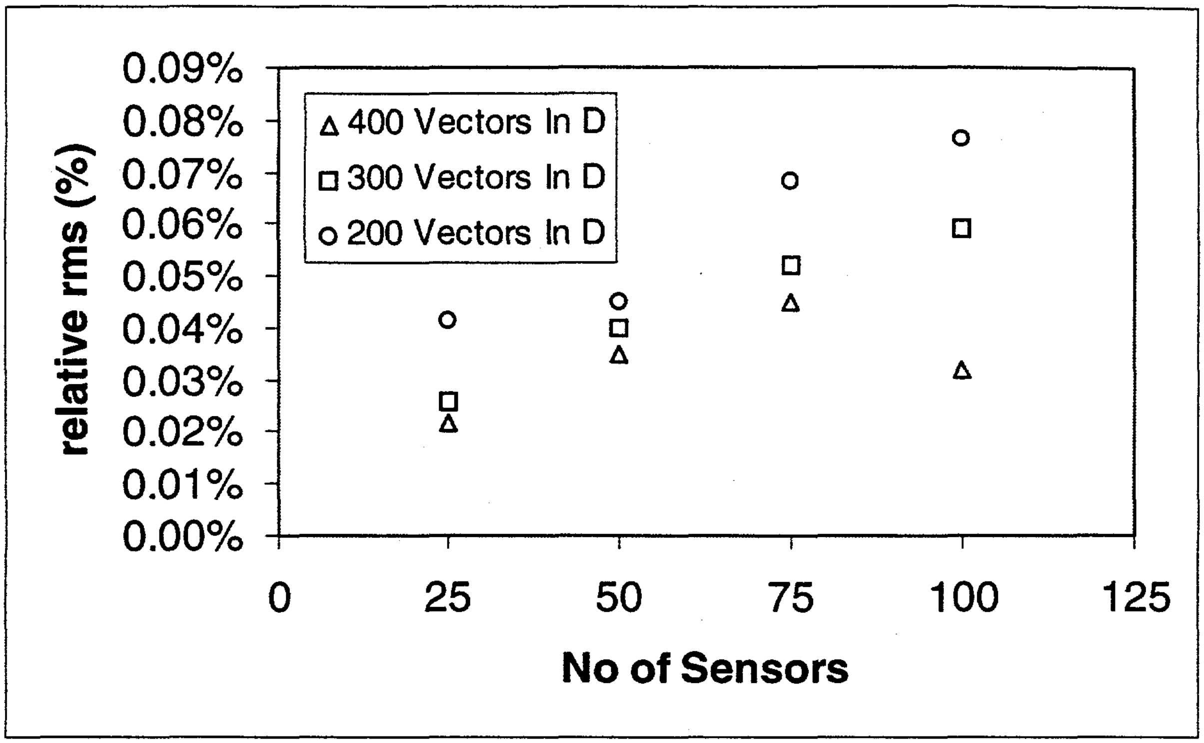

Figure 1 – The relative root mean square (rms) of the residuals, expressed in percentage, for venturi flow in loop B, as a result of using 25, 50, 75 or 100 sensors in the model, with approximately 200, 300 and 400 vectors in D for each model. Similar results, with similar values and identical trends were obtained for the loop A venturi.