Investigating the feasibility of using fuzzy logic-based method for transients classification in nuclear power plants

Piero Baraldi

The early identification of the causes for the onset of an unscheduled and meaningful departure from steady state behaviour is an essential step for the operation, control and accident management in nuclear power plants. The basis for the identification is that different system faults and anomalies lead to different patterns of evolution of the involved process variables. Given the safety and economical importance of the problem, several approaches for fault identification have been investigated and many efforts are continuously devoted to the improvement of the results thus far obtained.

The problem of fault identification may be tackled as a problem of classification. The classes are the different faults or anomalies of the plant, while the signals upon which the classification is based are the plant process variables. Our work has concerned the investigation of the capabilities of fuzzy logic in this area. One of the advantages of approaching the classification problem by fuzzy clustering is that the membership values found can serve as a confidence measure in the classification: for example, if a vector is assigned 0.9 membership in one class and 0.05 membership in two other classes we can be reasonably sure the class of 0.9 membership is the class to which the vector belongs. On the other hand, if a vector is assigned 0.55 membership in class one, 0.44 membership in class two, and 0.01 membership in class three, then we should be hesitant to assign the vector based on these results.

The key issue is the definition of a set of fuzzy *if-then* rules capable of associating the correct fault class to the various process variables transients which may occur. To this aim, we have developed a method of supervised training which automatically generates the proper rule corresponding to a given transient. We consider c possible transient-causing faults and suppose that a set of L numerical input/output vector pairs $(\overrightarrow{x_l}, q_l)$, $l = 1, ..., L$ is available from the plant. Each component x_l^i of $\overrightarrow{x_l}$ is a process variable and the corresponding q_l is an integer denoting the particular fault that has lead to the pattern evolution $\overrightarrow{x_l}$. These data are used to generate a set of fuzzy *if-then* rules representative of the correspondence between the input space of $\overrightarrow{x}$ and the output space of the fault class q. Once the training is completed, the fuzzy model is defined and one can feed it with a new input vector

$\overrightarrow{x}^*$ to determine the corresponding class q^*, i.e. the fault that has caused the plant transient. The method developed has been successfully applied to the classification of the causes of the transients in a steam genarator of a Pressurized Water Reactor (PWR): based on the measured signals, the forcing function responsible for the transient is readily classified.

The main disadvantage of the approach is the large number of rules of the resulting model. In our case, we obtained 266 *if-then* rules which are not physically interpretable so that the model is a "black box" not easily interpretable by the plant operators.

To improve this aspect, we are investigating the feasibility of using neuro-fuzzy systems and fuzzy clustering methods. In particular, with respect to the latter approach we would like to partition the process variables data into c clusters such that each cluster corresponds to one of the c fault classes.

In this area we have approached our investigation by looking at the popular Fuzzy C Means (FCM) method which searches for hyper-spheres or hyper-ellipsoidal clusters in the space of the input data. The FCM algorithm finds the centers of the c clusters and the degrees of membership of each of the L training data to each cluster, by iteratively minimizing an appropriately defined function which measures the distance, usually in an Euclidean metric, between the L data and the centers of the c clusters. The approach, however, is limited to a well defined geometric partition of the input data, thus depending on the metric assumed, and gives no a priori account to the fault class to which the data belongs. In our experience, this results in only only few of the identified clusters containing data actually belonging to a single class, the remaining clusters containing data belonging to more than one class. In this respect we are developing a method of data classification in which an evolutionary algorithm is employed to search for the optimal Mahalanobis metric on the basis of which the FCM algorithm derives a partition of the data set which accounts also for information on the fault class and is as close as possible to a priori known faults classification.