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NEW PROPOSAL OF REACTIVITY COEFFICIENT ESTIMATION METHOD USING A GRAY-BOX MODEL IN NUCLEAR POWER PLANTS

M. MORI[a], Y. KAGAMI[a], S. KANEMOTO[b], T. TAMAOKI[b], M. ENOMOTO[b], S. KAWAMURA[b]

[a]R&D Center, Tokyo Electric Power Company, 4-1, Egasaki-cho, Tsurumi-ku, Yokohama, 230-8510 Japan
[b]Power and Industrial Systems R&D Center, Toshiba Corporation 8 Shinsugita-cho, Isogo-ku, Yokohama, 235-8523 Japan

ABSTRACT

A new method for estimating reactivity parameters, such as moderator temperature coefficient (MTC) and void reactivity coefficient (VRC), is proposed using steady-state noise data. In order to solve the ill-posed problem of reactivity parameter estimation, a concept of a gray box model is newly introduced. The gray box model includes a first principle based model and a black-box fitting model. The former model acts as a priori knowledge based constraints in a parameter estimation problem. After establishing the gray box and noise source models, the maximum likelihood estimation method based on Kalman filter is applied. Furthermore, it is shown that the frequency domain approach of the gray box model is useful in the case of VRC estimation. The effectiveness of the proposed algorithms is shown through numerical simulation and actual plant data analysis.

KEYWORDS

boiling water reactor (BWR), reactivity estimation, moderator temperature coefficient, void reactivity coefficient, Kalman filter, maximum likelihood estimation, noise analysis.

1. INTRODUCTION

Monitoring of reactivity parameters, such as moderator temperature coefficient (MTC) or void reactivity coefficient (VRC), will be of prime importance in the future high burnup and Mixed Oxide (MOX) fuel assemblies. Noise analysis is an interesting technique for estimating these parameters since it enables them to be monitored without disturbing normal operations of the reactor. Hence, there have been many

attempts to develop estimation algorithms of MTC or VRC (Mori et al, 2004a, 2004b, Tamaoki et al, 2001, Shimazu, 1995, Demaziere et al, 2003, Andersson et al, 2003, Mori et al, 2003). However, it has also been pointed out that there are problems in that the estimated parameters are biased from the true values. Generally speaking, these parameter estimation problems are typical ill-posed problems, since the parameters should be estimated from a noisy and insufficient number of sensor signals. Hence, the estimation algorithm should be designed carefully by utilizing all knowledge about the problem.

The present paper proposes a new algorithm to solve the above ill-posed parameter estimation problem from noisy observations. The algorithm is based on the following three ideas (Mori et al, 2004a, 2004b):

1. A gray box model, which combines the first principle model (white-box model) and black box model (fitting model), is utilized in the parameter estimation algorithm. The first principle model plays a role of constraints in the ill-posed parameter estimation problem.
2. The system and observation noise sources are assumed in a gray box model to reconstruct noisy behavior of observation signals. The distinction of system and observation noise contributes to rational design of statistical parameter estimation criteria.
3. Parameter estimation criteria are assumed in both time and frequency domains depending on the problem features. The maximum likelihood estimation, which is the most rational algorithm in the statistical parameter estimation area, can be applied in the time domain approach. On the other hand, the frequency domain approach has a benefit of easily including heuristic knowledge in the criteria.

Concretely, the one point reactor kinetics equation for neutron dynamics is combined with an autoregressive fitting model for temperature or core flow dynamics. Also, it is assumed that the system noise sources are generated by temperature, void and core flow fluctuation. Once the system and noise dynamics model is assumed, the standard maximum likelihood parameter estimation algorithm based on Kalman filter can be used. Here, the gray box model is recognized as a priori knowledge based constraints as mentioned before. In the present paper, MTC will be estimated by this approach. It will be shown that this maximum likelihood based approach gives a good estimation result compared with the conventional method.

On the other hand, VRC should be estimated by another approach based on the frequency domain estimation criteria. The VRC estimation problem is more complex than the MTC one, since the key state parameter of void fraction cannot be directly observed. This means that the estimation results will be more sensitive to the modelling inaccuracies of system dynamics and noise sources. In order to overcome these inaccuracies, the heuristic estimation criterion defined in the frequency domain transfer function and coherence function is introduced in the present paper. The two kinds of statistical functions are necessary to estimate dynamic parameters and noise source magnitudes in the gray box model.

Although individual models and algorithms of the present paper are not new ones, their appropriate combination to address the essential feature of the problem will give better results than the conventional methods. The present paper shows these results through numerical simulation and actual plant data analysis.

2. GRAY BOX MODEL BASED PARAMETER ESTIMATION METHOD

2.1 Estimation Method of Moderator Temperature Coefficient

The present MTC estimation method is based on the following point kinetics reactor model.