Sensitivity Analysis of a Steam Generator Model Dynamic Output

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Keywords: sensitivity analysis, principal component analysis, bootstrap confidence intervals, thermohydraulic model, steam generator.

Abstract

Steam generators Pressurized light water nuclear power plants mainly consist of two separated water loops that exchange heat. The water from the primary loop goes first through the reactor itself where it is heated by the nuclear reaction and then through heat exchangers called *Steam Generators* (SGs) where it transfers heat to the water of the secondary loop. Secondary water is at much lower pressure (60 bars versus 155 bars for the primary water) so it boils when heated by the primary loop inside the SGs. The steam exiting the SGs by their upper opening flows through the turbines which produce the work eventually converted into electricity by alternators.

A SG consists of a cylindrical tank (approximately 20 meters high with a diameter of 3 meters) that contains the secondary steam-liquid mixture. The primary water enter the SG at its bottom and goes through a bundle a U shaped tubes. Thus, primary and secondary waters never mix and the heat exchange unfolds inside the metal the U-shaped tubes and at their internal and external interfaces. The tube bundle is maintained in place by circular plates called *Tube Support Plates* (TSPs). The TSPs have circular holes to allow for the passage of the tubes and these holes are surrounded by additional *quatrefoil holes* that allow for the passage of the secondary steam-liquid mixture.

Tube support plates clogging Steam Generators (SG) are affected by fouling of their internal elements by iron oxides present in the secondary feed-water. This causes clogging of the quatrefoil holes of the TSPs that can induce safety issues. Clogging reduces the open cross sectional area of the TSPs and thus induces higher pressure drop. This alters the operating point of the SG as well as its dynamic behaviour. Means to estimate TSP clogging are needed to optimize maintenance operations.

Previous studies (Midou et al., 2010) demonstrated that the shape of the Wide Range Level (WRL – the pressure difference measured between the steam dome and the bottom of the downcomer) response curve to a power transient is determined by the clogging state of the TSPs. A diagnosis method based on comparison between measured response curves and simulated ones for varying clogging states is being developed by EDF. For that purpose, a mono-dimensional SG model has been created with Modelica and the Dymola software. It is able to simulate the SG behaviour during power transient phases. A 60 % power decrease with a 3 $\%.min^{-1}$ rate is performed on French nuclear reactors every three months which allows for frequent diagnosis. The input variables of the model are the clogging ratios of each half TSP, one for the hot and cold legs of the U-tube bundle. Clogging ratios are defined as the ratio of the closed area to the total area of the holes without any clogging. The output of the model consists of the 1200 values of WRL (1 per second) given the clogging ratios of the 16 half TSP.

Sensitivity Analysis In order to achieve better understanding of the effect of clogging on SGs dynamic behaviour and to assess the potential of a diagnosis method based on analysis of this behaviour through simulations, it is necessary to determine *i)* what features of the WRL response curves are characteristic of clogging and *ii)* the relative impact of each half TSP on these features.

If it happens, for instance, that the clogging ratio of a given half TSP has a negligible influence, it is irrelevant to keep it as an input variable because little or no information about this ratio is

contained into the WRL response curve. Discarding irrelevant variables reduces the dimension of the clogging state space that has to be sampled to produce the diagnosis.

The objective of the present study is to analyse the sensitivity of the model output (WRL dynamic response) to its input parameters (TSP clogging ratios). A method based on the ANOVA-decomposition and a Monte Carlo computation scheme was used to compute order 1 and total sensitivity indices for each half-TSP (Sobol', 1993, 2001). Sequential indices were first computed and exhibited different behaviour for the hot and cold leg as well as four distinct phases during the transient. As the model output is functional, a principal component analysis (PCA) on the samples used to compute sensitivity indices had to be carried out to reduce the dimensionality of the model output and compute 'compact' order 1 and total sensitivity indices for each major principal component (Campbell et al., 2005; Lamboni et al., 2009). The model output has been reduced to the first two sets of loadings and two sets of order 1 and total indices have been computed. Finally, estimation variability was assessed by construction of BC_a bootstrap confidence intervals (Efron and Tibshirani, 1993; Archer et al., 1997). This permitted to check the validity of the conclusions drawn from the computed sensitivity indices and validate the presented methodology.

There are substantial combined effects for the upper hot leg TSPs only. Thus, although being not exhaustive, the present study can be considered as a thorough analysis of the effect of TSP clogging on SG dynamic. Results of the present study enabled to reduce the dimension of the diagnosis method input from 16 to 9. It also allowed to derive some physical assertions about the dynamic behaviour of clogged SGs as well as a convenient set up for further investigation of possible simplification of the problem.

Author presentation

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