Large scale applicability of a Fully Adaptive Non-Intrusive Spectral Projection technique: Sensitivity and uncertainty analysis of a transient

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Since the early years of reactor physics the most prominent sensitivity and uncertainty (S&U) analysis methods in the nuclear community have been adjoint based techniques. While these are very effective for pure neutronics problems due to the linearity of the transport equation, they become complicated when coupled non-linear systems are involved. With the continuous increase in computational power such complicated multi-physics problems are becoming progressively tractable, hence affordable and easily applicable S&U analysis tools also have to be developed in parallel.

For reactor physics problems for which adjoint methods are prohibitive Polynomial Chaos (PC) techniques offer an attractive alternative to traditional random sampling based approaches. At TU Delft such PC methods have been studied for a number of years and this paper presents a large scale application of our Fully Adaptive Non-Intrusive Spectral Projection (FANISP) algorithm for performing the sensitivity and uncertainty analysis of a Gas Cooled Fast Reactor (GFR) Unprotected Loss Of Flow (ULOF) transient. The transient was simulated using the Cathare 2 code system and a fully detailed model of the GFR2400 reactor design that was investigated in the European FP7 GoFastR project. Several sources of uncertainty were taken into account amounting to an unusually high number of stochastic input parameters (42) and numerous output quantities were investigated.

The results show consistently good performance of the applied adaptive PC methods, being superior to standard Monte Carlo sampling both in terms of accuracy and computational cost. This demonstrates that such PC techniques can provide a viable alternative to random sampling even for larger scale systems, which is especially appealing for the S&U analysis of problems using legacy codes common in the nuclear field.

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1. Introduction

Sensitivity and uncertainty (S&U) analysis is vital in augmenting simulation tools used on a daily basis in the design and operation of nuclear installations. Sensitivity analysis (SA) allows establishing a connection between the inputs used to describe the system being investigated and the calculated outputs, while uncertainty quantification provides means for estimating the uncertainties of these responses due to our lack of knowledge about the exact values of the design parameters. Sensitivity analysis can therefore provide a deeper understanding of a problem and ways for optimization, whereas uncertainty analysis can be used to demonstrate that important safety limits are respected with an appropriate level of confidence or to identify the main sources of the uncertainties that have to be reduced in order to decrease response variations to acceptable values. With Best-Estimate Plus Uncertainty (BEPU) methodologies gaining ground in licensing (Wilson, 2013) the development of affordable, fast and accurate S&U analysis techniques is expected to remain a prominent issue in the near future.

Numerous well-known methods are already available in the literature (Saltelli et al., 2000; Cauciu, 2003), which are traditionally divided into deterministic and stochastic approaches. The former ones include perturbation theory based techniques, such as generalized perturbation theory (GPT) in neutron transport (Gandini, 1967; Williams, 1986), while the latter ones are based on random or quasi-random sampling (Cauciu and Ionescu-Bujor, 2004). The popularity of GPT and adjoint techniques in general stems from the fact that with the solution of a single adjoint problem it is...