Annals of Nuclear Energy 63 (2014) 461–485

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Review

Effective spatial mapping for coupled code analysis of thermal-hydraulics/neutron-kinetics of boiling water reactors

Joanna Peltonen [a,*], Weimin Ma [a], Tomasz Kozlowski [b]

[a] Division of Nuclear Power Safety, Royal Institute of Technology, Alba Nova University Centrum, Roslagstullsbacken 21, SE 106 91 Stockholm, Sweden
[b] Department of Nuclear, Plasma and Radiological Engineering, University of Illinois at Urbana-Champaign, IL 61801, USA

ARTICLE INFO

Article history:
Received 22 April 2013
Received in revised form 25 July 2013
Accepted 26 July 2013
Available online 7 September 2013

Keywords:
BWR stability
Coupled TRACE/PARCS analysis
Spatial coupling
Hierarchical clustering

ABSTRACT

Analyses of nuclear reactor safety have increasingly required coupling of full three dimensional neutron kinetics (NK) core models with system transient thermal-hydraulics (TH) codes. In order to produce results within a reasonable computing time, the coupled codes use two different spatial description of the reactor core. The TH code uses few, typically 5–20 TH channels, to represent the core. The NK code uses one explicit node for each fuel assembly. Therefore, a spatial mapping of a coarse grid TH and a fine grid NK domain is necessary. However, improper mappings may result in loss of valuable information, thus causing inaccurate prediction of safety parameters. In this article the study of the effectiveness of spatial coupling (channel refinement and spatial mapping) and developed recommendations for NK/TH mapping are presented. The sensitivity of stability (measured by Decay Ratio and Frequency) to the different types of mapping schemes is analyzed against OECD/NEA Ringhals-1 Stability Benchmark data. Additionally, to increase the efficiency and applicability of spatial mapping convergence, a new mapping methodology is proposed. The new mapping approach is based on hierarchical clustering method; the method of unsupervised learning that is adopted in many different scientific fields, thanks to its flexibility and robustness. The proposed new mapping method is shown to be very successful for spatial coupling problem and can be fully automated allowing for significant time reduction in input preparation and mapping convergence study.

Contents

* Corresponding author. Tel.: +46 (0) 8 5537 8845; fax: +46 (0) 8 5537 8830.
E-mail address: joanna@safety.sci.kth.se (J. Peltonen).

0306-4549/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.anucene.2013.07.043

1. Introduction

1.1. Objectives

The present paper is concerned with the effectiveness and accuracy of coupled system codes for Thermal-Hydraulics/Neutron-Kinetics (TH/NK) analysis of boiling water reactors (BWRs).

When developing a new input model, system code users usually focus on time and space convergence of thermal-hydraulics, while paying little attention to the influence of the spatial mapping between the thermal-hydraulics and neutron-kinetics nodes. This is why the main objective of this research is to develop and validate a methodology for spatial mapping between the coupled TH/NK codes that enables higher accuracy as well computational efficiency in predicting the transients and accidents of safety importance. The aim is to establish an effective treatment of core thermal-hydraulics with a small number of representative channels while using full 3D neutron-kinetics solution.

Additionally, the study is performed to examine the tools, and to qualify the methods and the selected models of the coupled codes for analysis of BWR core stability. The evaluations of capabilities and limitations of the existing coupled TH/NK analysis is also an opening for improvements of multi-dimensional TH/NK coupling recommendations for effective TH/NK coupled treatment.

1.2. Background

Current computational tools allow for coupling of full three dimensional core neutronics models with system thermal-hydraulic codes, which gives an advantage of understanding the interaction between reactor core reactivity behavior and plant dynamics. The coupling of Thermal-Hydraulics/Neutron-Kinetics (TH/NK) provides new capabilities for understanding a Nuclear Power Plant (NPP) as a whole system including proper NK feedbacks. A BWR core has a large number of fuel assemblies (about 700 for a 1000 MW_{el} reactor) and the one channel per fuel assembly coupling of TH with NK models for such a core requires significant computational resources. Thus, there is a great interest in mapping optimization, to reduce the number of TH channels, while still maintaining desired accuracy. Usually, the TH code (e.g. RELAP5, TRACE) uses few, typically 5–20 TH channels to represent the core, while the NK code (e.g. PARCS) uses one explicit node for each fuel assembly. However, it is not clear if such small number of TH channels is enough to provide correct results prediction, therefore this research is aimed to resolve the issue of the spatial mapping of the reactor core between TH and NK models.

The mapping can be defined as a spatial grouping of NK nodes with TH channels and if it is not a full-scale (one fuel bundle-to-one TH channel), it entails a loss of important information in both directions TH ↔ NK, as described in Fig. 1. The increase in number of the TH channels leads to a loss of computational efficiency and in case of reactivity transients, these limitations can become significant.

1.3. Literature review

The problem of mapping has been discussed for many years by many researchers; however none of them has provided and sufficient approach for universal or generic mapping. The relevant publications and important conclusions are summarized below.

The authors of the paper (Todorova and Ivanov, 2001) performed sensitivity studies on spatial mesh overlays for PWR Rod Ejection Accident (REA). It was presented that REA simulation shows sensitivity to spatial coupling. Based on the results the authors concluded that TH feedback is non-linear and therefore cannot be separated in REA analysis.

The authors of the paper (Todorova and Ivanov, 2002) performed research on the sensitivity of coupled TH/NK system code's results to the spatial mesh, which was used for PWR transient analysis. Authors demonstrated that in case of asymmetric transients, geometric refinement has large influence on local parameters and control rod worth – NK mesh refinement impacts the local predictions in the same way as the TH refinement impacts global predictions. Because the local and global predictions are also sensitive to the TH refinement, the proper radial, axial nodalization

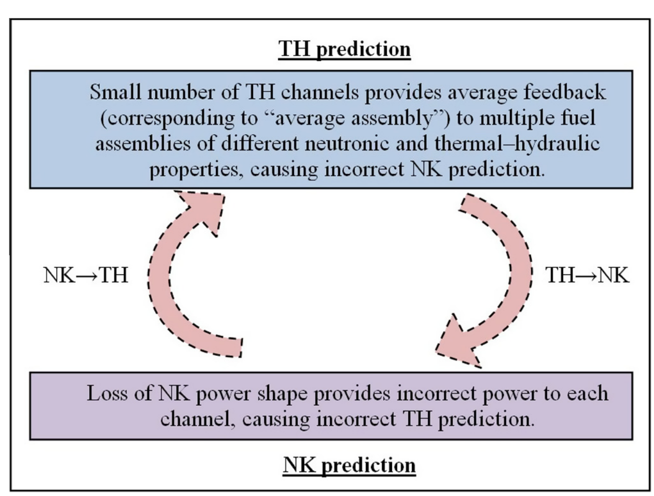

Fig. 1. Loss of information due to incorrect mapping.