Simulations of Dynamics and Control of Advanced Reactor Systems using Artificial Neural Networks

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INTRODUCTION

Recent technological developments in Next Generation of reactors have brought into focus high-efficiency heat energy converters needed for processing heat applications such as heat for coal gasification, enhanced oil recovery, ethanol production, and others.[1] While heat transfer/transport presents specific challenges of elevated temperatures and potentially large separation distances between nuclear and industrial plants dictated by safety and licensing mandates, to assure safety and commercial viability of these applications, advanced power units including heat transfer/transport components must have coordinated monitoring and operation features facilitating situational awareness and predictive response accounting for nuclear and non-nuclear machinery. These vital needs ultimately call for varied sets of complex and highly nonlinear systems and subsystems of increasing complexity that have to be focused on at the design and development stages as well as during the actual system operation. This complexity represents a significant challenge of paramount importance for the future of commercially viable next generation nuclear power units for process heat applications.

This paper focuses on the development and application of artificial neural networks (ANNs) specifically, the modeling, simulation, and robust control of heat transport systems for process heat applications in next generation of nuclear reactors. Awareness of novel techniques and tools and understanding of their advantages and further development needs contribute to the current state-of-the-art.

MODELING APPROACH

A high-fidelity dynamics model of the gas cooled reactor (prismatic type), intermediate heat exchanger, and process heat components is needed for data set generation necessary for proper training of ANNs on wide range of normal and off-normal plant operating conditions simulating nuclear power units for co-generation applications. Surrogate data may provide assistance in prototypic demonstrations and its potential for practical applications. The development can further be facilitated by experimental validation using operational data from existing systems including research reactors.

Robust intelligent control schemes with the goal of preemptively compensating for potential hazards based on early detection and prediction of future events is shown in Fig. 1.

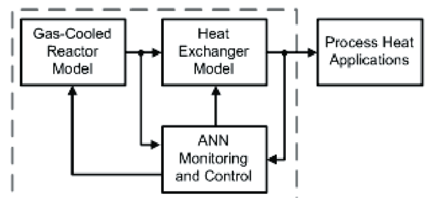


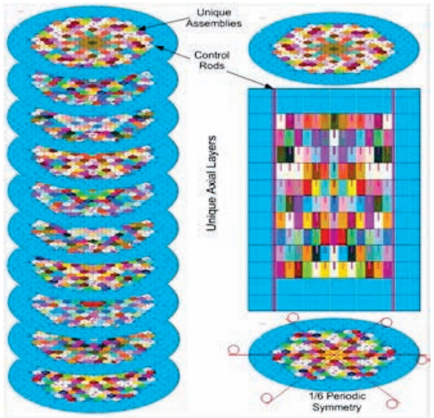
Fig. 1. ANN based control and monitoring scheme.

REACTOR ENVIRONMENT

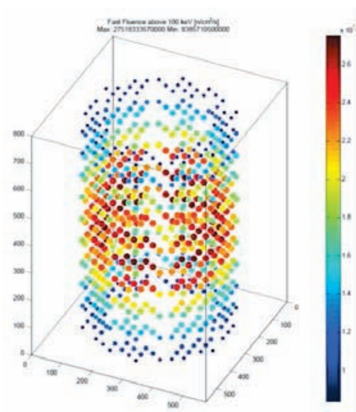
ANN methods are being applied to generation IV very high temperature reactors (VHTR), with the specific focus on the VHTR prismatic block configuration as a reference reactor design. A 3D whole-core exact-geometry model of a VHTR hexagonal-block configuration with a detailed component representation has been developed and implemented for calculations with MCNP/MCNPX and Serpent. The model is based on the NGNP pre-conceptual design features.[1] The modeling approach allows for development and applications of in-core 3D performance.

The developed representative NGNP VHTR modeling framework will be consistent with the NGNP pre-conceptual configuration targeting industrial heat applications and electricity.

The view of the high fidelity NGNP VHTR model is provided in Fig. 2 including the 3D high fidelity in-core mapping. The model color scheme demonstrates the ability to quantify physics characteristics while varying properties per block. It allows for tracking environments in fuel and coolant channels. To capture/reconstruct, visualize and evaluate performance characteristics, the detailed 3D maps are being produced at each block location with detailed performance/sensor data reconstruction.



(a) Whole core 3D VHTR model



(b) Localized performance characterization and 3D mapping.

Fig. 2. High fidelity whole-core VHTR model for core performance evaluations, hot spot identification, in-core characteristic mapping and 3D sensor data reconstruction and lifecycle analysis.

The model is based on the NGNP pre-conceptual design features.

CONCLUSIONS

This paper presented the concept and framework development efforts including the developed high fidelity models to yield the advanced design and optimization capabilities for next generation systems targeting process heat applications.

REFERENCES

1. "Next Generation Nuclear Plant Pre-Conceptual Design Report," INL/EXT-07-12967, INL (2007).