Dynamic Probabilistic Safety Assessment (PSA) of Small Modular Reactors (SMRs): Reduced Order Modeling and Advanced Sampling

In collaboration with TRACTABEL (ENGIE) - Engie Tower- Bruxelles - Belgium

Context of the research

Probabilistic Safety Assessment (PSA) is a key methodology used to evaluate risks in Nuclear Power Plants (NPPs). Traditional Level 1 PSA relies on Event Tree (ET) and Fault Tree (FT) analyses, which are static approaches and have limitations, including time-independence, binary component states, and predefined failure events, leading to conservatism and incomplete risk characterizations. This is particularly limiting when new concepts of NPPs, such as Small Modular Reactors (SMRs) are of concern.

Dynamic PSA (DPSA) overcomes these limitations by integrating a time-dependent system model with human operator models and stochastic failure models of the NPPs components. This enables accident sequences to emerge dynamically, improving the understanding of uncertainties, their quantification, and the exploration of accident scenarios for the design of safety systems that have to counteract their evolution to severe consequences.

Despite its advantages, DPSA is computationally demanding, as it requires numerous simulations. Reduced Order Modeling (ROM) and Advanced Sampling Methods offer a solution to the computational problems.

This thesis intends to contribute to advancing DPSA methodologies for SMRs safety analysis.

Objective of the research

This research aims to advance DPSA for the safety analysis of SMRs by resorting to Reduced Order Modeling (ROM) and Advanced Sampling Methods. The study will:

- Investigate ROM techniques (e.g., Gaussian Process Regression, Polynomial Chaos Expansion, Artificial Neural Networks) to reduce computational costs while preserving model accuracy.
- Explore advanced sampling strategies, such as Importance Sampling and Adaptive Sampling, to mine out rare accident scenarios.
- Compare DPSA results with traditional PSA approaches to evaluate accuracy and efficiency improvements.
- Identify methodological limitations and propose directions for future research.

Collaborations

Tractebel, part of the Engie Group, is a leading engineering firm specializing in energy and nuclear safety. The work will be performed in the Laboratory of Analysis of Systems for the Assessment of Reliability, Risk and Resilience (LASAR^3) of Politecnico di Milano in tight collaboration with TRACTABEL in Bruxelles (Belgium), where an internship is foreseen.

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