Advances in Reliability, Safety and Security

ESREL 2024
Collection of Extended Abstracts

Modelling Degradation And Ageing Phenomena In Digital Twin Using Profile Based Stochastic Hybrid Automata

Gaël Hequet[a], Nicolae Brînzei[a], Jean-François Petin[a],
Sophie Viot Coster[b], Didier Paen[c], Olivier Bruneau[c]

[a]*Université de Lorraine, CNRS, CRAN, F-54000 Nancy, France*
[b]*EDF R&D, 91120 Palaiseau, France*
[c]*CORYS, 38024 Grenoble, France*

Keywords: nuclear safety, degradation, ageing, profile-based stochastic hybrid automaton, digital reactor

In France today, nuclear power continues to play an important role, both in public opinion (Pratviel, 2022) and in French electricity generation. With a fleet of 56 pressurised water reactors, a large proportion of the electricity produced in France comes from nuclear power (62.7% by 2022) (RTE, 2023). It is against this backdrop that an innovative project has come into being, the Digital Reactor project (Levesque, 2021). This project, led by EDF, brings together 9 partners in the French nuclear industry to pool their know-how in pursuit of a common goal (EDF, 2022). This objective is the creation of a digital twin (Broo, 2021; Errandonea, 2020; Grieves, 2020) of a nuclear reactor enabling the modelling and representation of complex phenomena from design to operation, including maintenance phases. The aim of this digital twin is to become a tool for monitoring, training, and anticipating the future.

As part of this project, research is being carried out into the integration of dysfunctional modelling, considering ageing, degradation, and system failures. This will be done in a context of co-simulation, in which stresses can be injected. We therefore need tools capable of representing continuous phenomena as well as discrete events, while at the same time being able to modify its internal parameters during simulations and exploit external stresses.

Profile-Based Stochastic Hybrid Automata (PBSHA) (Hequet, 2021) were chosen to address these issues and needs. These tools, which are an extension of Stochastic Hybrid Automata (SHA) (Castañeda, 2011), enable a hybrid modelling of continuous physical phenomena and discrete events generated by command and control or representing the occurrence of failures (Chiacchio, 2016). With these properties, it is possible to simulate the evolution of systems over a certain period, which can be of the order of several years through Monte-Carlo simulation, to make the internal parameters of the models evolve. In the current work, the results of these simulations can then be recovered and used as initial conditions for a training simulator. A simulator in which time passes at the same speed as in the real world (real time) or in step-by-step mode has been developed and is the subject of this paper. The aim is to enable an external human operator to inject commands into the simulator and thus interact with the components modelled with PBSHA. The aim is to observe the impact of the state of the system on its behavior and on the operator's actions. To do this, a calculation engine has been created that allows Monte-Carlo Simulation as well as Real-Time simulation using the same models, while allowing communication with an external user (Figure 1).

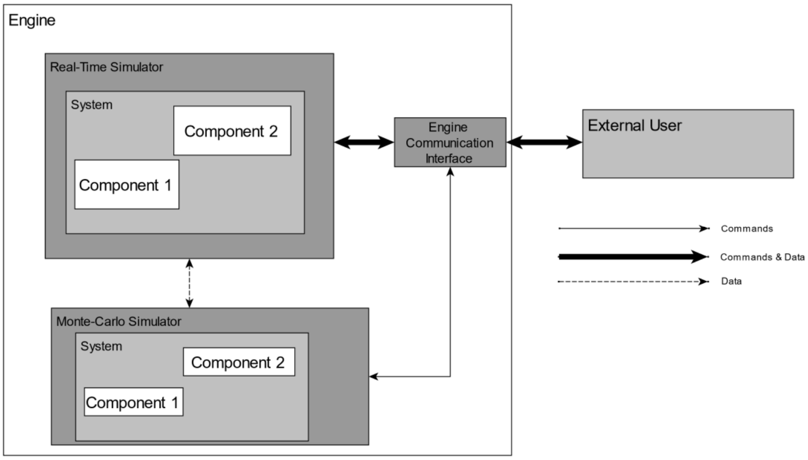

Fig. 1. Command and data exchange architecture for the calculation engine.

In order to observe the feasibility of this process with PBSHA, a system resulting from the APPRODYN research project (Babykina, 2016) is used in order to demonstrate the possibility of creating models enabling both accelerated-time and real-time simulations. This system is modelled using PyCATSHOO (Desgeorges, 2021) and is used to represent the difference in behaviour between a session at the beginning of a component's life and another after the component has aged.

Acknowledgements

This research work was supported by the “Digital Reactor” project funded by Public Investment Bank (BPI France) under the call for "Structuring Projects for Competitiveness" (PSPC) of the Future Investments Program (PIA).

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