World Academy of Science, Engineering and Technology
International Journal of Nuclear and Quantum Engineering
Vol:12, No:10, 2018

Multi-Objective Optimization of the Thermal-Hydraulic Behavior for a Sodium Fast Reactor with a Gas Power Conversion System and a Loss of off-Site Power Simulation

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Abstract : CEA and its industrial partners are designing a gas Power Conversion System (PCS) based on a Brayton cycle for the ASTRID Sodium-cooled Fast Reactor. Investigations of control and regulation requirements to operate this PCS during operating, incidental and accidental transients are necessary to adapt core heat removal. To this aim, we developed a methodology to optimize the thermal-hydraulic behavior of the reactor during normal operations, incidents and accidents. This methodology consists of a multi-objective optimization for a specific sequence, whose aim is to increase component lifetime by reducing simultaneously several thermal stresses and to bring the reactor into a stable state. Furthermore, the multi-objective optimization complies with safety and operating constraints. Operating, incidental and accidental sequences use specific regulations to control the thermal-hydraulic reactor behavior, each of them is defined by a setpoint, a controller and an actuator. In the multi-objective problem, the parameters used to solve the optimization are the setpoints and the settings of the controllers associated with the regulations included in the sequence. In this way, the methodology allows designers to define an optimized and specific control strategy of the plant for the studied sequence and hence to adapt PCS piloting at its best. The multi-objective optimization is performed by evolutionary algorithms coupled to surrogate models built on variables computed by the thermal-hydraulic system code, CATHARE2. The methodology is applied to a loss of off-site power sequence. Three variables are controlled: the sodium outlet temperature of the sodium-gas heat exchanger, turbomachine rotational speed and water flow through the heat sink. These regulations are chosen in order to minimize thermal stresses on the gas-gas heat exchanger, on the sodium-gas heat exchanger and on the vessel. The main results of this work are optimal setpoints for the three regulations. Moreover, Proportional-Integral-Derivative (PID) control setting is considered and efficient actuators used in controls are chosen through sensitivity analysis results. Finally, the optimized regulation system and the reactor control procedure, provided by the optimization process, are verified through a direct CATHARE2 calculation.

Keywords : gas power conversion system, loss of off-site power, multi-objective optimization, regulation, sodium fast reactor, surrogate model
Conference Title : ICNTHS 2018 : International Conference on Nuclear Thermal Hydraulics and Safety
Conference Location : Paris, France
Conference Dates : October 29-30, 2018

Open Science Index, Nuclear and Quantum Engineering Vol:12, No:10, 2018 publications.waset.org/abstracts/86881.pdf