RELAP5-3D Dynamic Coupling Capability Applied to Nuclear Hybrid Energy System Modeling

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Dynamic code coupling capability with RELAP5-3D has been developed and exercised for over a decade at INL and other US government laboratories. Application of RELAP5-3D and its Parallel Virtual Machine (PVM) Executive program to Nuclear Hybrid Energy Systems (NHES) is under consideration.

NHES can employ a nuclear reactor's heat output for various applications other than just the electricity grid. In an integrated multi-output system, thermal energy from the nuclear reactor subsystem can be diverted to industrial applications in times of low electricity demand. High temperature, high quality heat from advanced reactor designs might be used for hydrogen production or synthetic fuel production (coal-to-liquid or natural gas-to-liquid processes). Low temperature heat from advanced reactor designs or the current and future fleet of light water reactors (LWRs) might be applied to desalination processes or be stored for later use in low temperature ammonia or hydrocarbon-based thermal cycles.

Of course, many computational tools and methods are available for modeling a nuclear reactor, power conversion systems and associated process applications. One method is to develop a single program capable of modeling an entire NHES system. Another is to combine two or more existing computer programs, each modeling a portion of the system for which it is validated, where the programs exchange information to compute the solution. The former method requires a lengthy development and verification and validation process for each NHES. The latter method leverages industry standard software to reduce development and funding requirements. RELAP5-3D, with its PVM Executive program, provides a natural method to combine a program that models the nuclear reactor subsystem with programs modeling other NHES subsystems. *Further, since the best programs for modeling a given NHES differ according to the processes being integrated, different sets of programs are best suited for modeling different NHES, and RELAP5-3D/PVM Executive provide a uniform method to coordinate their coupling*.

The INL NHES research team is currently developing a dynamic simulation of an integrated hybrid energy system. A detailed simulation of proposed NHES architectures will allow initial computational demonstration of a tightly coupled NHES to identify key reactor subsystem requirements, identify candidate reactor technologies for a hybrid system, and identify key challenges to operation of the coupled system. This work will provide a baseline for later coupling of design-specific reactor models through industry collaboration.

Alternative system models have been developed by INL researchers and are currently being enhanced to assess integrated system performance given multiple sources (e.g., nuclear +

wind) and multiple applications (i.e., electricity + process heat). Initial efforts to integrate a Fortran-based simulation of a small modular reactor (SMR) with the balance of plant model take advantage of an existing SMR model developed at North Carolina State University to provide initial integrated system simulation for a relatively low cost.

As the system model is enhanced, there is significant interest in adopting an industry standard software package to model the reactor subsystem and other integrated system components. The RELAP5-3D code is both a nuclear industry standard and provides the necessary dynamic coupling technique to connect to other component and subsystem simulations. This approach will allow adoption of standard simulation platforms used by researchers outside the nuclear field, recognizing that nuclear hybrid energy systems represent truly cross-cutting system architectures that bring together researchers from a wide range of industries and experience.

NHES could be a key part of the solution to achieving energy security, may provide reliable power availability even with increasing renewable energy penetration into the power grid, and may allow repurposing excess electricity in times of low demand. Incorporating a fission-based power source in a multi-output system (electricity and process heat) can offer significant advantages over carbon-based production sources, such as coal or natural gas, including reduction in atmospheric carbon emissions. RELAP5-3D could become an important component in the design modeling and safety analysis of NHES.