A High Fidelity Model and Code Generator for the Simulation of BOP Systems

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Introduction

The introduction of the RETACT™ code in 1985 for the real time simulation of Nuclear Steam Supply Systems (NSSS) thermalhydraulics represented a significant advance in modeling fidelity. Since then simulator vendors have introduced several high fidelity models for modeling Core Neutronics. These include the STK and REMARK models by S3 Technologies. Improvements were also made to the Balance of Plant Systems (BOP) models, but these did not provide the same high level of fidelity as the primary system models.

Today, simulator owners are emphasizing the need for improving the BOP models. The new ANS3.5 standard draft requires a one percent fidelity on critical parameters. However, European plant designs, with their higher level of control automation, require a better than one percent tolerance from models of plant physical processes. This has been one of the prime objectives at S3 Technologies in developing the high fidelity TOPMERET™ model for BOP systems.

Additional design objectives for TOPMERET included automation in code generation, constants calculation and variable definitions for direct placement in a database. Code generation provides a high level of software quality and standardization. Model implementation and maintenance process can be quick and easy, and less specialized skills are required for this process. TOPMERET can also be integrated with S3 Technologies Graphics User Interface (GUI) for added user friendliness and productivity.

Description

Because TOPMERET was designed for BOP systems, it had to be extremely flexible to accommodate a variety of systems, including Main Steam, Feedwater, Turbine, Condenser, Offgas, large volumes, such as the Containment, and water systems such as Service Water. Since the basic fluid flow, thermal and transport processes are similar for these systems, the challenge was to develop a single coherent modeling system that could handle the variety of plant components and the diversity of flow and heat transfer regimes found in these systems.

TOPMERET incorporates the following basic features:

> Two phase (Gas and Liquid) multi component (H_2O, N_2, O_2, and H_2) nonthermal equilibrium model that lets you select any combination of these

options to reduce computer time. For example, for a cooling water system where two phase calculations are unnecessary, it is possible to select only liquid phase.

- Separate Mass, Momentum, and Energy Balances for each phase, removing any need that the two phases be in equilibrium. It is also possible to have any combination of liquid/gas concurrent or countercurrent flow pattern.

- The model calculates all the physical and transport properties, including pressures, gas and liquid flows, enthalpies, (gas, liquid, and wall temperatures), heat transfer rates (gas-wall, liquid-wall, gas-liquid, wall-ambient), gas phase concentrations, boiling and condensation rates, densities, activities, conductivity, and boron concentrations.

- Besides simulating the transient and steady state operating conditions of plant systems, TOPMERET also handles the filling and draining of pipes, smooth transitions to hydraulic pressure, pipe breaks, interfacing system Loss of Coolant Accidents (LOCA) and back flow of air in broken pipes.

- Unit independence makes it transportable between different systems. You specify the system of units to work in. This information is then reflected in the constant derivations and the constant and variable descriptions.

Reference [1] discusses the modeling equations used in TOPMERET in detail.

Verification and Validation Results

We tested and delivered the basics of this solution method on the Forsmark 1 simulator for a single node model in the Scram Tank System. The new model gives excellent pressure and flow results under all conditions.

We tested the multinode model on a stand alone system with 4 nodes and 12 flow paths. The TOPMERET solution gave good results during all phases of testing including:

- Filling and draining of pipes and tanks
- Single and two phase flows
- Counter current gas-liquid flows
- Centrifugal pump flow and pressure
- Boiling and condensation flow
- Mass and energy balance checks
- Transition from gas to hydraulic pressure and back.

TOPMERET has been successfully tested and verified in the integrated environment on the Barsebaeck 1 simulator in Sweden for the Main Steam Lines. The trainer was declared ready for training in November 1991. It has 22 pressure nodes and 95 flow paths. It performed well under all phases of operation, including Main Steam line warmup, 0 to 100% power, Main Steam line breaks, and other transients.

TOPMERET has been configured and tested offline for the Ringhalls 1 main steam and turbine system from the outlet of the reactor vessel to the condenser. It gave very good results for all power levels with an average error in total shaft work of under 1%.

Summary

TOPMERET represents a significant advance in the modeling fidelity of BOP systems. It handles both normal and abnormal operating scenarios, including pipe break accidents. It has tested successfully on various simulators, and meets the fidelity required of BOP system models so as to successfully integrate with the high level of control automation of European designs.

References

[1] Galen T. Stanley, 1992. "TOPMERET Two Phase Mass Momentum and Energy Balances in a Real Time Environment." Proceedings of the 1992 SCS Eastern Simulation MultiConference, Orlando, Florida.