APROS simulation models for transient thermal hydraulic analyses of Forsmark's NPPs

Peter Balint, peb@forsmark.vattenfall.se
Lisa Bladh, lbl@forsmark.vattenfall.se

An emerging need of plant compatibility[1] analyses

In the coming years power up-rates of the three Forsmark reactors are planned. Forsmark 1 and 2 will increase the thermal reactor power from today's 108 %, 2928 MW_{th} to 120 %, 3253 MW_{th}. The power up-rate includes replacing components in the reactor vessels as well as exchange and redesign of parts in other process systems and modifications of control and automation systems. An example of major changes in the process is forward pumping of condensate flow from HP feed water heaters. The condensate will be pumped forward into the feed water lines upstream of the reactor with new installed pumps instead of letting the condensate flow go through cascade coupling back to the condensate water cleaning system.

As a result of changes and modifications in the plant process and control systems there is an increased need to be able to perform plant compatibility analyses. The analysis tool APROS (Advanced Process Simulation Software) provides the possibility to simultaneously simulate the dynamics of the complete steam cycle with reactor, turbines, condenser, feed water system and control and automation systems. APROS is developed by Technical Research Centre of Finland (VTT) in cooperation with Fortum Nuclear Services Ltd (FNS). In APROS, comprehensive process models can be set up using detailed physical models with high accuracy.

As a first step, an APROS as-built model of Forsmark 2 was developed by Fortum for Forsmarks Kraftgrupp (FKA) in 2008. The model is validated against plant transient measurements. Currently the Forsmark 2 model is being updated to a power up-rated version. Also, efforts to develop an as-built model of Forsmark 3 are ongoing.

The program

APROS is a multifunctional simulation environment for the dynamic simulation of nuclear and conventional power plant processes and for the simulation of industrial process dynamics. In APROS, two phase flows, nonequilibrium thermodynamics, reactor kinetics, heat transfer, advanced automation systems and electrical systems can be modelled. The reactor core can be modelled with a one or three dimensional neutronics model.

There are three different thermal hydraulic models available in APROS. In the most advanced thermal hydraulic model, called the six-equation model, the thermal hydraulic equations are based on the conservation equations of mass, energy and momentum for the liquid and gas phases. There is also a five-equation model available, where the momentum equation is solved for a mixture of gas and liquid. For applications where it is not necessary to separate

[1] Compatibility in this document is used as equivalent of the Swedish word ”samfunktion”. By compatibility analysis it is meant analysis that shows how different parts in the plant process systems interact and work together with the rest of the plant.

the gas and liquid phases, a homogenous three-equation model can be used to achieve faster simulations. In APROS different thermal hydraulic models can be used simultaneously in different sections of the model.

APROS is provided with a graphical interface GRADES. In GRADES, the model input data is specified in graphical components. The components of the different nuclear power plant subprocesses are organised in separate sheets called nets, forming flow charts that are easy to grasp. The simulations can be executed through GRADES, where also simulation results can be plotted while running the simulation.

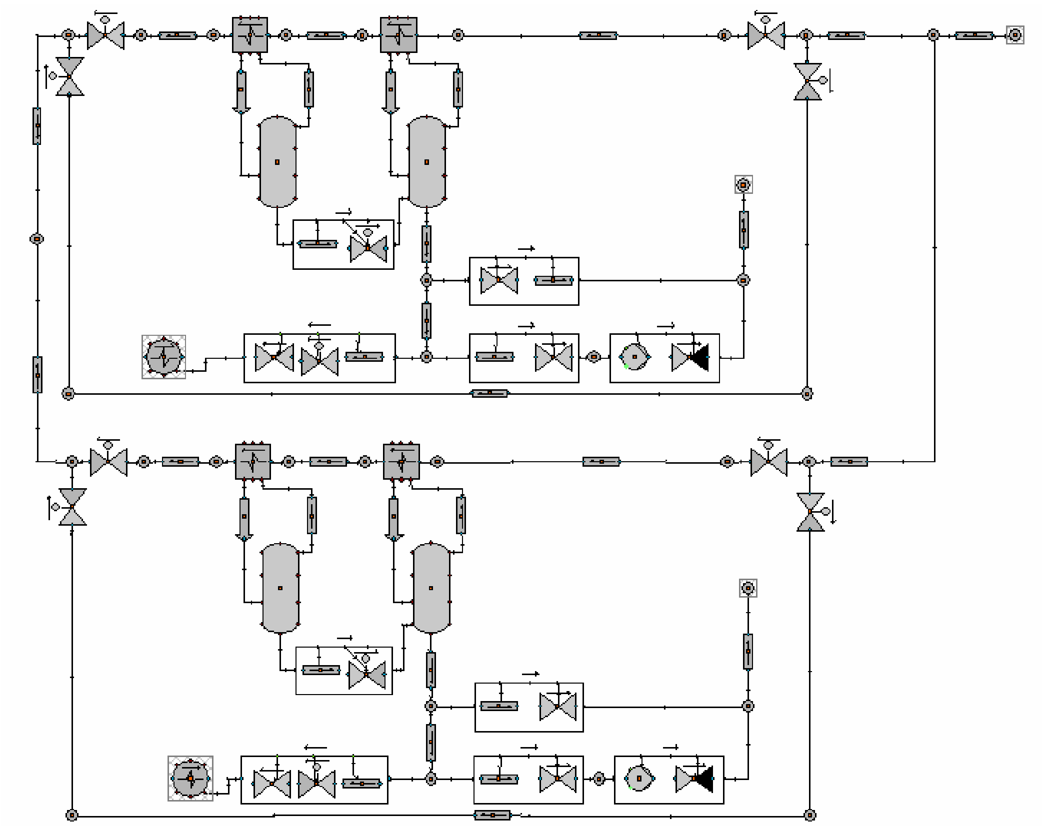

Figure 1. Part of feed water system of F2 as modelled in APROS graphical user interface GRADES

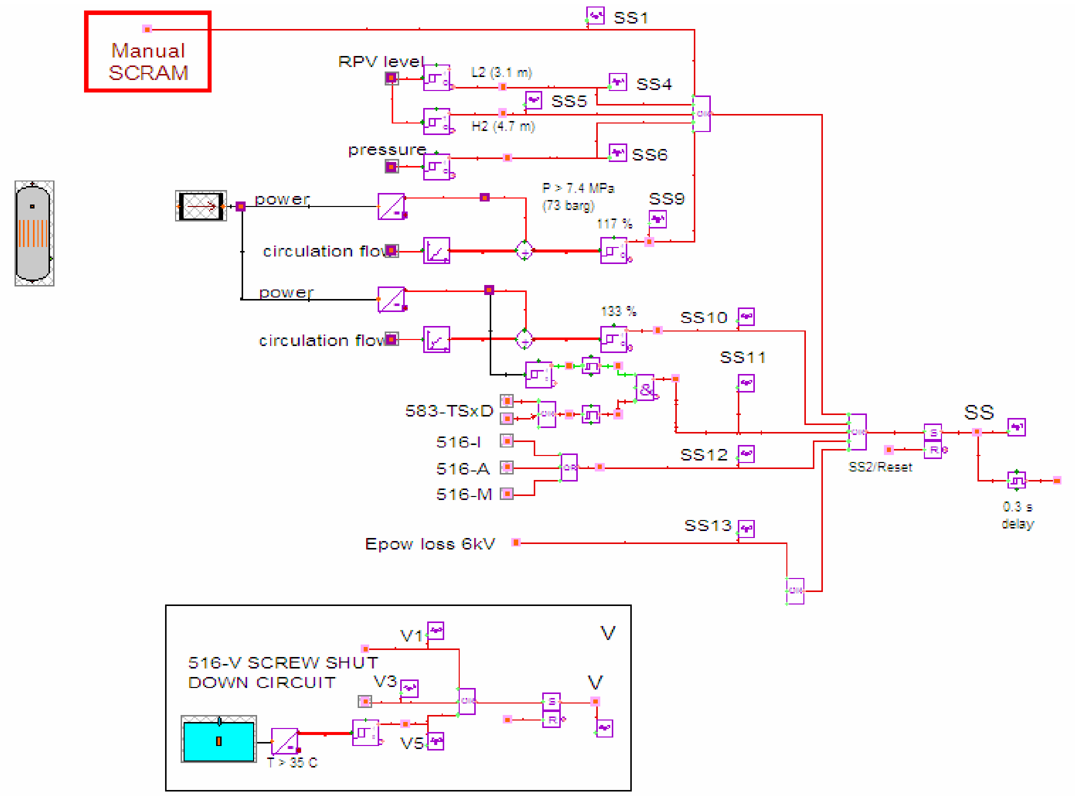

Figure 2. Part of reactor safety system of F2 as modelled in graphical user interface GRADES

The model

The model of Forsmark 2 includes process, automation and electrical systems essential for engineering and analysis purposes. Generally, the six-equation model has been used in the reactor vessel and in the main steam lines within the main steam control valves. Outside these boundaries, both the six-equation and the three-equation models are used. Use of the three-equation model results in increased simulation speed.

The reactor vessel and its internal components are set up with correct volumes and heat structures where the reactor is modelled as a 1D-neutronics model. The core power can be controlled by the position of the control rods, where the separate control rod groups are set up. The full process model is set up including the emergency systems, the containment, the main steam lines, the high and low pressure turbines, the condensers, the condensate system and the feed water system. The different subsystems are supplemented with their control and automation systems. In addition, a smaller model of the electrical system is set up, including the turbine generators, the main transformers, main switches and the external net.

Validation of the model

The Forsmark 2 model has been validated through comparison of simulations and of measurements of transients in the plant.

The validation simulations show good agreement with measurement data, with a few exceptions which can be attributed to use of the more simple three-equation calculation model.

At the Inspecta Symposium – Kärnteknik 2008, some of the F2 model validation simulations with APROS will be presented.