Systém a řízení kompenzátoru objemu VVER 1000 v prostředí Dymola

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VVER 1000 Pressurizer System and Control Modelling in Dymola

Abstract – **The pressurizer is responsible for controlling the pressure and temperature in the primary circuit of the nuclear power plant. It is basically a pressure vessel, filled partially with water and partially with steam at saturation state. The controlling process can be described by two regimes, either by the self-control regime or by the automatic control regime. This paper is describing the simplified automatic control regime on the model of the pressurizer in the primary circuit of VVER 1000 made in Dymola software with the ClaRa library. Reactor power change and corresponding steam generator power change are the actuators in the simulation. The behaviour of the coolant level and pressure in the pressurizer is simulated in the model and it is then compared with data provided by the supplier of VVER 1000.**

Keywords – ClaRa; Coolant level; Dymola; Pressure; Pressurizer

I. VOLUME COMPENSATION SYSTEM ON VVVER 1000

The main purpose of the volume compensation system is to:

- Compensate the coolant volume in primary circuit caused by small temperature differences
- Maintain the pressure in the primary circuit during bigger differences caused by changes the primary or secondary circuit
- Heating up and cooling down the pressurizer
- Continuously increase or decrease the pressure during heating up or cooling down the primary circuit

- Secure the primary circuit during accident regimes, caused by a prompt pressure increase

The whole system consists of pressurizer YP10B01, bubbler-condenser YP20B01, steam dumping pipeline with two safety valves YP22S01 and YP23S01, relief valve YP21S01. Relief and safety valves are part of the safety systems while spray system and pressurizer are part of safety-related systems. [1] [2] [3] [4]

A. PRESSURIZER MODEL

The model of the pressurizer used in this paper is based on the ClaRa library model. The model structure is defined as in the fig.I.

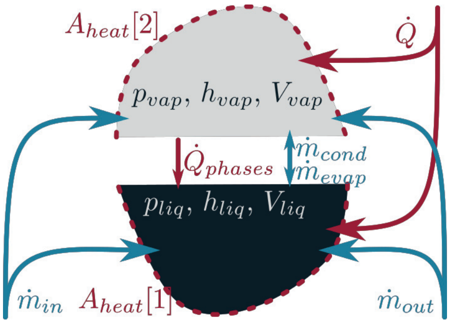

Figure I. **ClaRa Two-phase control volume model structure [9]**

Two distinct zones are considered (vapour and liquid). They can exchange mass and heat. This model deals with conservation of mass (example given for vapour zone):

$$\frac{d\rho_{vap}}{dt}V_{vap} = \dot{m}_{in,vap} + \dot{m}_{out,vap} - \dot{m}_{cond} + \dot{m}_{evap} - \rho_{vap}\frac{dV_{vap}}{dt} \quad (1)$$

and the conservation of energy:

$$\frac{dh_{vap}}{dt} = \frac{1}{m_{vap}}\Big(\sum_{i=1}^{N_{in}} \dot{m}_{vap,in,i}\, h_{in,i} + \sum_{j=1}^{N_{out}} \dot{m}_{vap,out,j}\, h_{out,j} + \dot{m}_{evap}h_{dew} - \dot{m}_{cond}h_{bub} + p_{vap}\frac{dV_{vap}}{dt} + V_{vap}\frac{dp_{vap}}{dt} - h_{vap}\Big(V_{vap}\frac{d\rho_{vap}}{dt} + \rho_{vap}\frac{dV_{vap}}{dt}\Big) - \dot{Q}_{phases} + \dot{Q}_{vap}\Big) \quad (2)$$

The pressurizer (Fig. II.) has three physical connectors, namely inlet, outlet and heat. The inlet is the inlet of the spray system, outlet is a connection to the “hot leg” and heat connector represents electric heaters. [5] [6] [7] [8] [9]

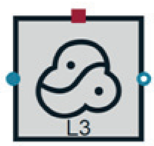

Figure II. **ClaRa Two-phase Model design [9]**

II. RESULTS

The functionality of the complex model (fig.III.) was validated on simple simulation, with the constant reactor power output. Properties of the model and components behaviour were observed and evaluated in following figures. All foregoing simulations were performed with following initial conditions as shown in table I.

TABLE I. INITIAL CONDITIONS

Pressure in the pressurizer	15,7 MPa

Coolant level in the pressurizer	8,175 m
Properties of the "cold leg" • between SG and MCP • between MCP and Reactor	h = {1280;1320} kJ/kg p = {15;15,1} MPa h = {1280;1320} kJ/kg p = {15,5;15,6} MPa
Properties of the "hot leg" • between reactor and fitting • between fitting and SG	h = {1450;1480} kJ/kg p = {15,55;15,6} MPa h = {1460;1490} kJ/kg p = {15,5;15,55} MPa

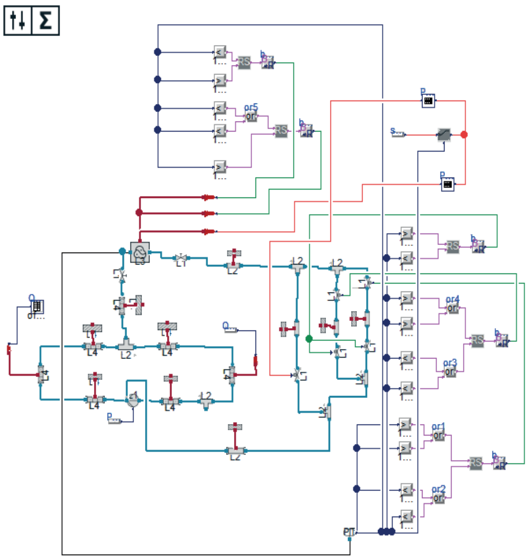

Figure III. **Complex model of the control system**

A. Transient simulation - failure of one main circulation pump (MCP)

The last set of figures show the simulation of transient caused by the failure of one MCP in the whole system. When there is a failure of one MCP, the mass flow rate in the affected loop is rapidly decreased and so is the average temperature of the coolant in this loop. The other loops are responding to the increased flow rate, but due to this, the average temperature of these loops is decreased. During this transient, the EHs are put into operation and valves are closed. The reactor power is at the beginning rapidly decreased to 55%, and then it stabilizes on 55% after 200 s as shown in the fig.IV.

The simulated pressure decreases correspond to the reality, but the gradient is not as large, and so the minimal value (at 80 s) reaches only 15,25 MPa and then returns to the original value. The behaviour of the simulated temperature in the primary circuit (fig. VI.) is very close to the real behaviour. So, the reason for the difference in the pressure behaviour is most likely caused by the fact, that the system is too stiff and the pressurizer is too optimistic, i.e. introduces smaller action than required.

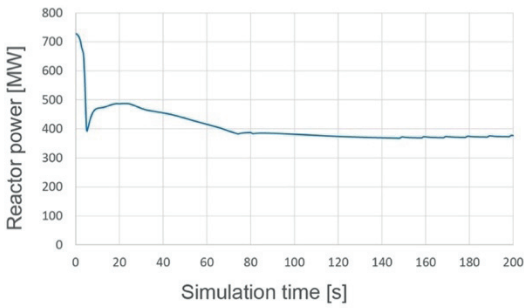

Figure IV. **Reactor power output**

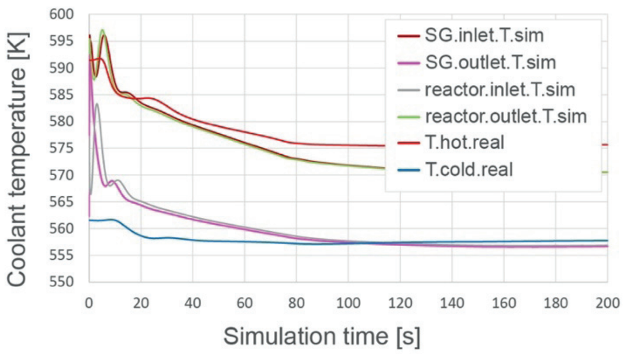

Figure VI. **Temperature in the primary circuit**

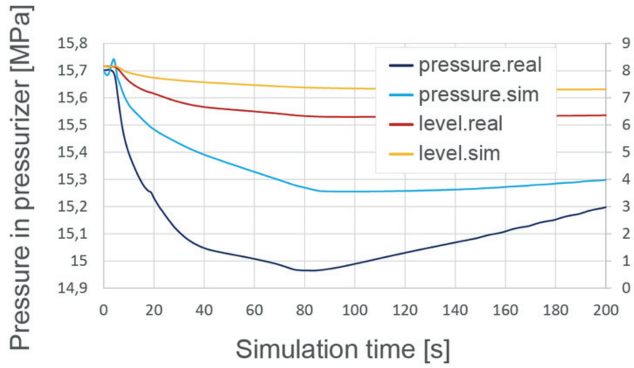

Figure V. **Pressure and the coolant level in the pressurizer**

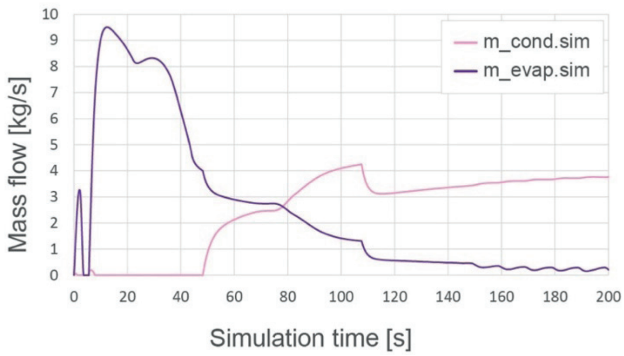

Figure VII. **Condensing/evaporatin g mass flow**

Since the system is composed of two zones, different processes are occurring in each zone throughout the simulation. The pressurizer is trying to deal with the load change, and thus the final vapour mass is increased, and the final liquid mass is decreased(fig.V).

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REFERENCES

[1] Cs. Fazekas, G. Szederkényi, K.M. Hangos "A simple dynamic model of the primary circuit in VVER plants for controller design purposes".

[2] A. Gábor, K. M. Hangos, G. Szederkényi, "Modeling and Identification of the Pressurizer of a VVER Nuclear Reactor for Controller Design Purposes".

[3] Csc. Ing. Jaroslav Rubek, Control and Automation of Nuclear Energy Devices, 2016.

[4] CEZ, Monitoring and Control System VVER 1000, Instumenration and Control System, 2008.

[5] CEZ, Primary circuit VVER 1000, 2008.

[6] CEZ, Main Regulation on VVER 1000, 2004.

[7] C. o. A. DYNCAP/DYNSTART, "ClaRa 1.2.2 library," 2017.

[8] CEZ, Input Data for Safety Analysis, 2015.

[9] EGP, Unit Operation Regimes VVER 1000, Prague, 2012.