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Improvement of NSSS T/H Module ARTS for SG level transients of YGN #1/2 Simulator

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1. Introduction

KEPRI(Korea Electric Power Research Institute) developed a realistic nuclear steam supply system thermal-hydraulic(T/H) module, named ARTS code, based on the best-estimate code RETRAN for the improvement of the KNPEC(Korea Nuclear Plant Education Center) unit 2 full-scope simulator[1,2,3]. In this work, we make a nuclear steam supply system thermal-hydraulic module for the YGN 1/2 nuclear power plant simulator using a practical application of a experience of ARTS code development.

The volume method for the steam generator(SG) which considers real SG geometry is used for KNPEC#2 simulator. This method shows somewhat transient behavior but water level mismatches during the low power operation. The mass method which uses the result of the code GNEF was adapted to the YGN#1 simulator at the beginning of this project. Using this method, water level was accurate all over the power operation range but does not show the swell and shrink. For this reason we changed the T/H module with collapsed level which utilizes both of the liquid mass and vapour mass in the steam generator. The advantage of this method is that it gives more accurate level calculation and shows somewhat better water level transient than the volume method. To improve the water level transient effects of the YGN#1 simulator we added a lead compensator which uses steam pressure changing rate for the input to the T/H module. The simulation results show much more improved swell and shrink phenomena of the water level.

The rest of the paper is structured as follows, the Steam Generator modeling is described in Section 2. In Section 3 Controller Module Design is explained and followed by the simulation results. Finally, in Section 4, the conclusions of the paper are presented.

2. Steam Generator modeling

The transfer function of the u-tube steam generator model of the nuclear power plant relating the feed-water flow-rate u and the steam flow-rate d to the narrow range water level y is given by[4]

$$y(s) = \left(\frac{G_1}{s} - \frac{G_2}{1+\tau_2 s}\right)\ \left(u(s) - d(s)\right) \tag{1}$$

In (1) all constants are positive. G_1/s is the mass capacity effect of the SG. It integrates the flow difference $u(s)-d(s)$ to calculate the change in water level. $-G_2/(1+\tau_2 s)$ is the thermal negative effect caused by the "swell and shrink"

For the simulator the first term, integrated water level, in (1) is calculated by the T/H module. We added a lag compensator (the second term in equation (1)) to the ARTS module but the result shows the smooth change of water during the transient. Normally, the swell and shrink phenomena are fast and sharp transient. So, we adopted a different method for the steam generator model in the T/H module for the simulator.

We recognize that the physical swell/shrink phenomena are caused by the pressure change in the steam generator. So, we changed water level calculation scheme of the ARTS as follows:

$$y(s) = \left(Collapsed\ LVL\right) + K\left(\frac{\tau_1 s}{1+\tau_2 s}\right)\Delta P_s(s) \tag{2}$$

where ΔP_s is the steam pressure changing rate between the time steps. The collapsed level is calculated by the ARTS module which is based on the best-estimate code RETRAN. The second term is devised for the thermal negative effects.

The second term in (2) can be transformed to the discrete time domain as

$$L_2(k) = \frac{\tau_1}{T+\tau_2}P_d(k) - \frac{\tau_1}{T+\tau_2}P_d(k-1) + \frac{\tau_2}{T+\tau_2}L_2(k-1) \tag{3}$$

where $L_2(k)$ is the S/G water transient level at time k, $P_d(k)$ is the steam pressure difference between time step k and $k-1$ and T is the sample period which is 0.0416 second for our T/H module.

3. Controller Module Design

Our goal for the controller design is that the swell period is 20 seconds and the settling time is as short as possible. To find optimum lag time τ_2 we examined several parameters for several cases while keeping the τ_1/τ_2 constant, i.e., $\tau_1/\tau_2 = 7$ as shown in Table 1. In this test the contribution rate K of the transient level to the integrated water level was fixed to 0.01. We opened one of the steam dump valve at 100% power operation.

τ_1	τ_2	Swell period	Max. Level(%)	Settling Time($\pm$0.3%)
17.5	2.5	20″	50.69	4´3″
35	5	22″	51.01	3´58″
70	10	1´40″	51.31	30″
280	40	2´ 10″	51.54	10´ 08″
560	80	2´ 30″	51.70	10´ 35″

Table 1. The transient effects of changing τ_2

The settling time for the transient is defined as the elapsed time from the valve operation to the water level decrease and stay within 50±0.3%. From the Table 1, we can notice that the swell period and settling time gets longer for bigger τ_2. As the swelled water level disappears within 20 seconds in real plant, τ_2 is needed to be increased because this parameter determines the exponential decrease of level. But according to the Table 1 the appropriate τ_2 is around 5 seconds, i.e., quite small. This is caused by the fact that the swell in the simulator does not caused by only one step pressure change but many serious changes in the simulator. From the results of the Table 1 we choose τ_2 as 5 seconds because the swell period does not last long time in real plant.

If τ_1 / τ_2 is less than 1, the transient water level is smooth but the settling time is longer as we expected.

With chosen τ_2 we tested T/H module for several τ_1 / τ_2 keeping τ_2 constant 5. For this test the multiplication rate K is adjusted to reveal the same swell amplitude of 5% when the condenser dump valve is opened. Finally, we accepted the following parameters for the controller.

$$K = 0.05, \quad \tau_1 = 35, \quad \tau_2 = 5 \tag{4}$$

4. Simulation Results

We operated the steam dump valve(AE-TV-414) for the simulation test of the improved T/H module at 100% full power operation. The valve was opened at 120 seconds and closed at 480 seconds after the simulator ran.

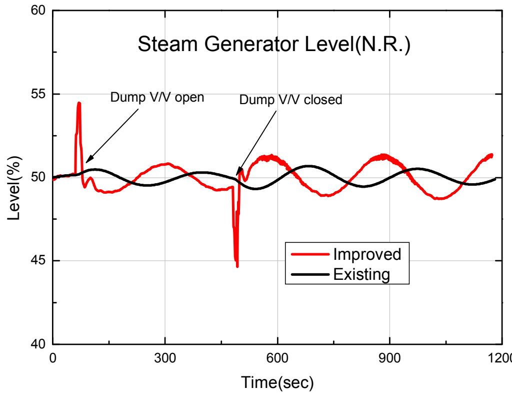

Figure 1. Steam Generator Water level responses of the Original & Improved ARTS during the condenser dump valve open/close

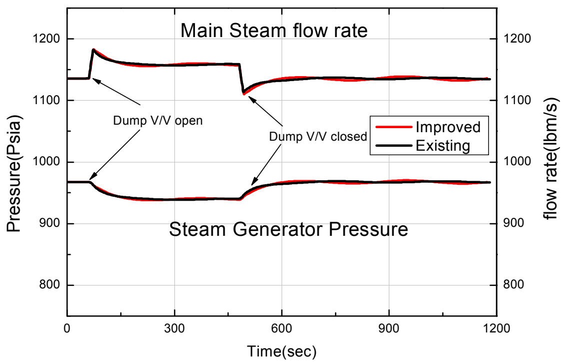

Figure 2. Steam flow rate and steam pressure during the condenser dump valve open/close

In Figure 1 the narrow range water level swells and shrinks about 5% and disappears within 20 seconds after improving the T/H module. But the water level for the original T/H module does not shows any swell and shrink except the integrated level change caused by the flow rate difference between feed water and steam. Figure 1 shows the improved water level transient effect.

Figure 2 illustrates the change of the steam generator pressure and steam flow rate when the condenser dump valve open/close. This figure shows that the simulation conditions for both cases are the same.

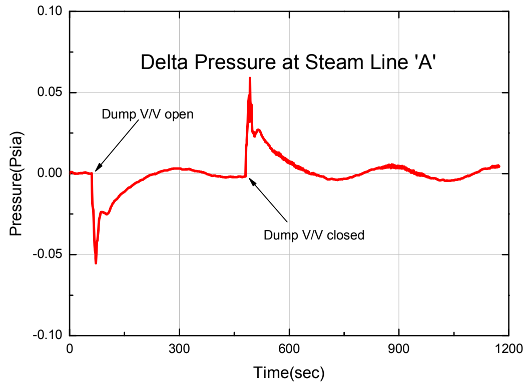

Figure 3. Steam pressure changing rate during the condenser dump valve open/close

Figure 3 shows the steam pressure changing rate which used for the input of the controller in equation (3). It shows the maximum pressure difference between the adjacent time steps during the one condenser dump valve open is about -0.05 psia.

5. Conclusion

We improved the steam generator water level transients of the YGN#1/2 simulator by adding the lead compensator in the ARTS module. Because we used plant information from the experienced plant operator, the controller parameters like τ_1, τ_2, K should be readjusted for accurate modeling after acquiring the real plant trend data. Moreover, for the immoderate steam pressure change during the turbine trip or main steam line brake accidents the lead compensator should be reconstructed because the transients show different phenomena.

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