Prediction Analyses of Feedwater System Transients in Lungmen Nuclear Power Plant Startup Tests with PCTRAN

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ABSTRACT
Prediction analyses of Lungmen Nuclear Power Plant (NPP) startup transient tests have been successfully conducted using a fast, efficient simulation code, Personal Computer Transient Analyzer (PCTRAN). In this paper, we have analyzed two startup transients on feedwater system and its related parametric sensitivity studies. The first one is the “loss of feedwater heating accident”; the other one is “feedwater pump trip accident”. Different initial operating conditions, recirculation runback rates were considered. In this study, we present our prediction results on important system parameters such as temperatures, water levels, and flow rates for these two transients. Comparisons of parameters with those from another simulation code, TRAC/RELAP Advanced Computational Engine (TRACE) and Reactor Excursion Leak Analysis Program 5 (RELAP5) of Lungmen NPP show good agreements. After different sensitivity studies, we have the confidence that PCTRAN could be a tool for training the nuclear power plant operators.

Key words
Feedwater system transient analysis, PCTRAN, ABWR, Lungmen Nuclear Power Plant

1. Introduction
The Micro-Simulation Technology (MST) Company has been developing a reactor simulation software named PCTRAN for decades [1]. PCTRAN is a personal computer based nuclear power plant transient simulation code using reduced thermal hydraulic nodes and direct calculation for its fast event response analysis. It can simulate a variety of accident and transient conditions for nuclear power plants. The code were built on Visual Basic programming (VB) language and run under Windows (XP, Vista, 7) environments at a speed much faster than the real-time. With the use of graphical user interface (GUI), the code is user-friendly and easy to operate. See Figure 1.

So far, the Taiwan power company (TPC) is striving to build up the first advanced boiling water reactor (ABWR) NPP, Lungmen, in Taiwan. A series of startup transient tests have to be conducted before its commercial operations. At present, large and complicated system codes, such as TRACE, RELAP5, and RETRAN are being used to simulate these tests and see whether the current Lungmen designs meet all acceptance criteria. Without a time-consuming thermal hydraulic calculation, the advantage of fast responses of PCTRAN simulation code may be a proper software for reactor operators to have a preliminary understanding of the system response trends of all kind of event. In this paper, we have analyzed two startup
transients on feedwater system and its related parametric sensitivity studies. The first one is the “loss of feedwater heating accident”, the other one is “feedwater pump trip accident” [2]. We have also made comparisons with the results from TRACE [3] and RELAP5 [4].

2. Loss of Feedwater Heater

2.1 Event description

This event was modeled as a 40 second ramp down in feedwater temperature from the initial feedwater temperature. Upon sensing a temperature decreasing, we initiate reactor internal Pump (RIP) runback and selected control rod run-in (SCRRI) as a response to the transient. The increase in subcooling collapses the voids that increases the void reactivity and reduces water level in the core. SCRRRI reduces the reactivity of the core and core temperature. RIP runback reduces the reactor power and decreases the recirculation flow rate.

2.2 Result and Discussion

To aid in evaluating the criteria for other operating conditions and performances, additional sensitivity studies were performed and the results are presented in the following figures. The selected parameters in the sensitivity study were feedwater temperature reduction, and initial power.

Fig. 2 plots the feedwater temperature predicted in PCTRAN for three different degrees of feedwater heater loss. At the beginning of the transient, the feedwater temperatures decrease due to the loss of feedwater heater for 40 seconds and then keep at constant values. At this time, SCRRRI is initiated too. Fig. 3(a-b) shows the comparison between PCTRAN and
RELAP5 of average surface heat flux. At the beginning of 40 seconds, the surface heat flux has a slight increase due to the colder feedwater input in both curves. The surface heat flux decreases soon after SCRRI initiation. The result of our PCTRAN data has a good agreement to RELAP5. Fig. 4 presents the positive void reactivity due to the void collapse and shows acceptable consistent trends in PCTRAN.

![Fig. 2 The feedwater temperature variations in PCTRAN for different feedwater temperature drops.](image1)

![Fig. 3(a-b) The comparisons between the average surface heat flux variations in PCTRAN for different feedwater temperature drops and RELAP5 data.](image2)
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Fig. 4 The void reactivity variations in PCTRAN for different feedwater temperature drops.

Figures 5-7 present the variations of the results on sensitivity studies of the different initial power levels. Figure 5 plots the curves of average surface heat flux. As a result, the average surface heat flux is varied by the different initial power from 80%, 90% to 100%. Even though the initial powers are different, all of them approximately have the same trend. Figure 6 plots the void reactivity curves. Because of the negative void feedback, the void reactivity have a slight increase due to the decrease in feedwater temperature. After SCRRR initiation, the void reactivity also increases due to power drops. Figure 7 compares the water level above the separation skirt between PCTRAN and RELAP5. It reveals that PCTRAN data have a rising trend during the beginning 40 seconds. Then, the water levels increases at faster rates due to the decease in RIP flow rate and runback. Due to the set point difference, the beginning of water level of PCTRAN is 5 cm shorter than RELAP5, and the PCTRAN water levels have the slight difference than RELAP5, during the transient accident.
3. Feedwater Pump Trip

3.1 Event description

At the beginning of the transient, one of the two normally operating turbine-driven feedwater pumps tripped. The turbine driven feedwater pump reduces to zero flow in few seconds. Upon sensing the reduction of feedwater flow rate, the motor-driven feedwater pump and RIP runback start up automatically. The feedwater flow is 65% rated at 5 second and up to 75% between 10 to 30 seconds after the motor-driven feedwater pump starts.
3.2 Result and Discussion

The following figures show transient responses of important plant parameters. To aid in evaluating the criteria for other operating conditions and performances, additional sensitivity studies are performed and the results are presented in the following figures, too. The selected parameters in the sensitivity studies were maximum feedwater capacity and motor-driven feedwater pump delay time.

Figures 8-10 present the results for cases of different feedwater capacities. Figure 8(a-b) plots the feedwater flow rate curves of three different feedwater capacities of PCTRAN model and RELAP5 model. The feedwater flow rates drop immediately in the PCTRAN modeling. Upon sensing the reduction of feedwater flow rate, the motor-driven feedwater pump automatically starts and provides additional 20% of the rated feedwater flow. It is obvious that the Feedwater flow rate of RELAP5 has a special increasing during 5 to 10 second. That is because the RELAP5 model has over design the motor-driven feedwater pump capability, which makes the feedwater resupply greater than usual. Figure 9 shows the downcomer water level variations. In PCTRAN, the water levels have similar trends compared with TRACE data. The water levels for all of the feedwater capacity cases under study do not reach the low level scram set point, (1307 cm).

Figure 10 plots the core inlet subcooling temperature in PCTRAN. Higher feedwater capacities result in larger core inlet subcoolings.

(8-a)                                    (8-b)
Fig. 8(a-b) The comparisons between the feedwater flow rate in PCTRAN for different maximum feedwater capacities and RELAP5 data.
Fig. 9(a-b) The comparisons between the reactor water level above separation skirt in PCTRAN for different maximum feedwater capacities and TRACE data.

Fig. 10 The core inlet subcooling temperature in PCTRAN for different maximum feedwater capacities.

Figures 11-13 show results for the case of different motor-driven pump start up time sensitivity studies in PCTRAN. Figure 11 plots the feedwater flow rate curves that show an obvious result that we have postponed the motor-driven pump start up time in 1, 5 and 7 seconds. Figure 12 and 13 present the core inlet subcooling temperature and reactor water level results. All of our operation conditions on different motor-driven start up time have close trends. Figure 13 shows that the water levels of motor-driven start up time delay in 1, 5, and 7 seconds. Even for the 7 seconds delay case, water level does not reach the low-level scram set point, 1342 cm.
Fig. 11 The feedwater flow rates in PCTRAN for different motor-driven pump start up time.

Fig. 12 The core inlet subcooling temperatures in PCTRAN for different motor-driven pump start up time.
4. Conclusions

PCTRAN is a personal computer based simulation code using reduced thermal hydraulic nodes and direct calculation for its fast event responses analysis in nuclear power plant transient analysis. With the use of GUI, the code is user-friendly and easy to operate. In this paper, we concentrated on two feedwater system related startup transient predictions and sensitivity studies of some important parameters. The first one is the “loss of feedwater heating accident”, and the other one is “feedwater pump trip accident”. Different initial operating conditions, recirculation runback rates were considered. In this study, we present our prediction results on important system parameters such as temperatures, water levels, and flow rates for these two transients. Comparisons of vessel water level variations with those from another simulation code RELAP5 and TRACE of Lungmen Nuclear Power Plant show good agreements. Modifications and adjustments of the PCTRAN models will be conducted when Lungmen NPP starts initial fuel loading.

REFERENCES