A Quick Review on Steam Generator Water Level Tracking Methods and Its Uncertainties

Ki Moon Park*, Jeong Ik Lee
Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, 373-1 Guseong-dong Yuseong-gu,Daejeon 305-701, Republic of Korea
**Corresponding author: powermoon@kaist.ac.kr*

1. Introduction

The function of a steam generator (SG) in a Pressurized Water Reactors (PWR) is to transfer heat from the Reactor Cooling System (RCS) to the secondary power conversion system side. The tracking of the SG water level is important for maintaining the heat removal of the reactor and the power plant safety. In addition, the SG water level is important for the reactor trip and the actuation of SG back-up feedwater system as well. The SG water level is mainly controlled by the Feed Water Control System (FWCS) during either normal operation or transients therefore, the selection of the FWCS control parameters is also important.

However, the SG water level cannot be tracked with a direct measurement. Therefore, many indirect measurements or estimations can be applied to the SG water level tracking. To understand the relationship of measured variables and the actual SG water level, a system analysis code is often used. Thus, it is important to set up a computational platform to investigate the correlation of an indicator of the SG water level at steady-state and transients to the actual SG water level to optimize the FWCS.

In this paper, methods of SG water level calculation are first reviewed and future works to perform sensitivity study of the SG water level calculation with a system analysis code will be identified.

2. Method and Review

It has been identified in the previous works that three parameters can be used as an indicator of the SG water level. These parameters are: (1) SG downcomer collapsed water level, (2) water mass inventory and (3) pressure differential between upper and low tap of SG.

2.1. Downcomer Collapsed Water Level

The difficulties in designing the SG water level controller arise from thermal dynamic effects of ‘‘shrink and swell”, which are more prominent at start-up and low power range of operation. This phenomenon is due to the two phase mixture of steam and water present in the tube bundles [1].

The collapsed water level is computed by summing the product of the void fraction and volume length over the control volumes in the downcomer section [2]. As mention in 2.1.1, dynamic effects of ‘‘shrink and swell” is needed to be considered when simulating FWCS for analyzing transient which are related to the feedwater system (i.e.: loss of feedwater, increasing feedwater, total loss of feedwater and so on)

2.2. Water Mass Inventory

Wei Dong introduced a new feedwater control strategy for the SG. The new method directly controls water mass inventory instead of downcomer water level, eliminating complications from shrink and swell all together [3]. The following ten measurable parameters are chosen as the inputs for the neural network to perform the water mass inventory estimation:

$$\mathrm{m} = \mathrm{f}(\mathrm{L}, \frac{\partial L}{\partial t}, W_s, W_1, W_{fw}, T_{1cold,} T_{1hot}, T_{fw}, P, \frac{\partial P}{\partial t})$$

Where:

L is downcomer water level
W_s is steam flow rate
W_1 is primary side water flow rate
W_{fw} is feedwater flow rate;
T_{1hot} is primary side hot leg temperature
T_{1cold} is primary side cold leg temperature
T_{fw} is feedwater temperature
P is steam pressure

This new control strategy is not influenced by dynamic effects of ‘‘shrink and swell”, but it should be verified via experiment, comparing and analyzing relationship of the SG downcomer collapsed water level and water mass inventory.

2.3. Pressure Differential

The pressure differential measurement is the most widely used method for estimating the SG water level in experiment as well as in the industry. The relationship of the pressure differential to the SG water level can be shown from the Bernoulli equation:

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 \quad (1)$$

$$\Delta P = \frac{\rho (V_1^2 - V_2^2)}{2} + \rho g (Z_1 - Z_2) \quad (2)$$

Where:

V is the fluid flow speed
g is the acceleration due to gravity,
Z is the elevation of the point above a reference plane,

P is the pressure at the chosen point, and
ρ is the fluid density

As it can be observed from the above equation, the downcomer collapsed water level and pressure differential are governed by ρ (the fluid density) which is related to the void fraction profile of the SG secondary side. Thus tracking the SG water level with the pressure differential may include some uncertainties due to the void fraction profile effect. Furthermore, the void fraction profile will vary during different operating conditions. Thus, further evaluations are needed to study the effect.

This is partially shown from Loss-of-feedwater experiments carried out in PACTEL and the LOF-10 experiment [4]. The experiment was chosen to test the modeling capabilities of TRACE code for VVER SG [5]. The experiment measured the water level with the pressure differential and the code calculated the water level directly from the code results. However, a few unexplained discrepancies exist between the two models and the authors presume that the difference may result from the difference in the estimation of the water level.

3. Summary and Further Works

In this paper, three previously suggested parameters which can be used as an indicator of the SG water level are briefly introduced: (1) downcomer collapsed water level, (2) water mass inventory and (3) pressure differential.

From the review of previous works, it was identified that most of the system analysis code calculates the SG water level directly by using the downcomer collapsed level. In contrast, the pressure difference is measured as used for the SG water level tracking in a real nuclear power plant [6] or experiment.

Therefore, the authors think that the system analysis code results have to be re-evaluated to check for the consistency between the pressure differential measurement and the downcomer collapsed water level. Furthermore, the authors have quickly shown that the void fraction profile can influence the water level tracking uncertainties. Thus, the SG sensitivity of the current pressure differential measurement based SG water level tracking method to secondary side void fraction profile has to be further studies not only for the steady-state operation but also under various transient scenarios.

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