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Tuning PI controller for APR 1400 Feedwater control system

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1. Introduction

As a part of the non-control system in the Advanced Reactor Power (APR) 1400 nuclear power plants, the Feedwater control system (FWCS) automatically controls the steam generator water level by regulating the feedwater flow rate from the startup mode to operation mode. However, controlling the steam generator (SG) water level is one of the most difficult problems in the nuclear power plants, particularly at a lower power level. This is because that the thermodynamic phenomena, known as Swelling and Shrinking are potential to happen in the SG. If there is the failure to control the SG water level which leads to unexpected shutdown scenarios, this will affect operation life and safety of the APR 1400 nuclear power plants. In this study, in order to enhance to perform of the SG water level at different power levels, it is necessary to design the new controller which is the proportional integral (PI) controller to improve the performance of the FWCS.

2. APR 1400 Steam generator

The APR 1400 is a Pressurized Water Reactor (PWR) plant with two loops, one SG and two reactor coolant pumps in each loop, and it generates 1400MW of electrical power overall [1]. The SGs are vertical U-tube heat exchangers with an integral economizer. The integral economizer operates with the reactor coolant on the tube side and secondary coolant on the shell side [2].

The SG is one of the dynamic components in the PWR plant. The functions of the SG are to yield the major heat sink to the nuclear reactor and to produce high pressure steam for power conversion. Therefore, it is important to control accurately the feedwater flow to the SG [3].

3. Simplified APR 1400 Feedwater control system

The required feedwater flow is computed by processing the summed error signals through the PI controller. In the low power region (below 20%), the difference between a compensated SG downcomer water level signal and the level setpoint, and the SG level error signal to generate a flow demand signal. This flow demand signal is sent to a downcomer feedwater control valve program. Thus, the feedwater flow rate is regulated by the downcomer feedwater control valve. In the high power region (above 20%), the difference between a compensated SG downcomer water level signal and the level setpoint is combined with the difference between the total feedwater flow and total steam flow signals. The flow demand to the downcomer feedwater control valve program is set to an adjustable bias setpoint which positions the downcomer valve to pass approximately 10% of full-power feedwater flow. Feedwater flow rate is regulated by the economizer feedwater control valve and main feedwater pump speed [2]. Fig. 1 illustrates the simplified schematic diagram of the APR 1400 FWCS.

3.1 Controller of the FWCS

The control performance of the FWCS dominantly relies on the PI controller that includes a gain and a reset time constant. The gain (K_1) and the time constant (τ_8) of the PI feedwater controller fluctuate as a function of reactor power as illustrated in Fig. 1. The compensation networks and the setpoints are installed so that the SG water level control properly during transient and steady-state conditions.

There are several drawbacks when adding a derivative control action to the controller as described in Fig. 1. Firstly, it is more difficult to accomplish an expected performance because three parameters in a proportional–integral–derivative (PID) controller all collaborate and must be balanced. A second drawback involves to the uncertainty in the derivative calculation for processes which have noise in the measurement signal. This is because that the derivative action results in the noise in the measured signal to be amplified and reflected in the controller output [3].

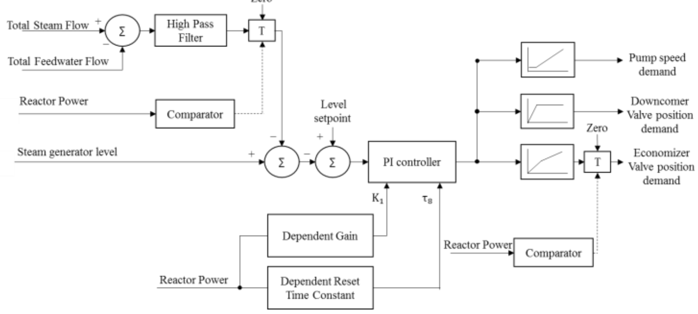

Fig. 1. Simplified schematic block diagram of feedwater control system

4. Methods and Results

There are various different reactor power levels between startup mode and full power operation mode. In this section, 100% power is selected to design the new PI controller for the FWCS. The new controller is achieved by the PID Tuner in MATLAB [4].

4.1 Tuning PI controller

The PID Tuner app automatically tunes the gains of a PID controller for a single-input-single-output (SISO) system to obtain a compromise between performance and robustness. In this study, the PI controller type is specified in this app. The PI controller tuning appears easy, but finding the set of gains that assures the best performance of the FWCS is a complicated task. The basic structure of the PI controller is shown:

$$G(s) = k_p\left(1+\frac{1}{\tau_i s}\right) \quad (1)$$

Where k_p is the gain and τ_i is the time constant of the PI controller [5]. A system consists of a plant and a controller with unity feedback is shown in Fig. 2.

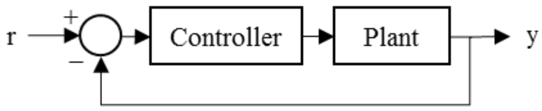

Fig. 2. Simple closed-loop system with plant and controller

In order to design the PI feedwater controller of the APR 1400 SG, the SG model is identified as a simple transfer function through measured data by System Identification Toolbox [4].

4.2. Simulation of the new PI controller

After employing the PID Tuner app to tune the parameters, the new PI feedwater controller is accomplished with the parameters as follow

$$G(s) = k_p\left(1+\frac{1}{\tau_i s}\right) = 3.291\left(1+\frac{1}{0.074s}\right) \quad (2)$$

The step response of the closed-loop system depicts the improved performance and robustness of the FWCS as described in Fig. 3. This is due to the fact that the performance and robustness is shown in Table 1.

Table 1. Tuned values of performance and robustness

	Tuned values
Rising time	13.3 seconds
Overshoot	18.4%
Closed-loop stability	stable

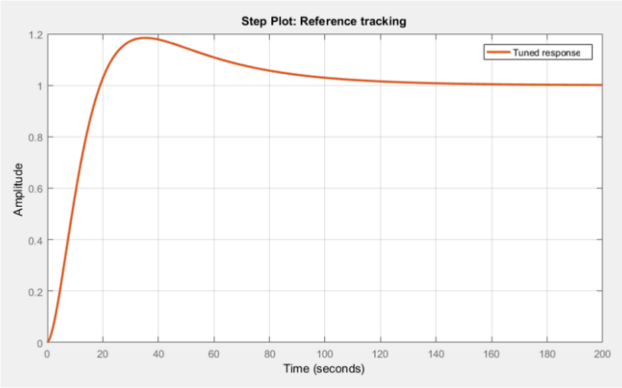

Fig. 3. Step response of the closed-loop system for the tuned feedwater PI controller at 100% reactor power

5. Conclusion

Simulation technique using the PID Tuner app, MATLAB can be a useful tool for tuning the PI controller of the FWCS. The technique is to find the optimized parameters of the PI controller so that the FWCS increases the efficiency performance and robustness. In this study, the PI controller of the FWCS at only 100% power is tuned and simulated. It is demonstrated the effectiveness of this technique. Similarly, the feedwater PI at other power levels can be tuned to improve the performance of the FWCS. As a result, the SG water level is controlled properly at different power ranges, particularly the low power level.

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