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PI Controllers in Performance Analysis Computer Code for Nuclear Power Plants

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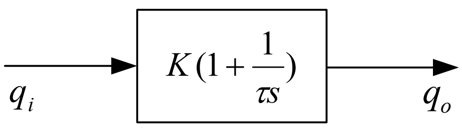
1. Introduction

There are many proportional integral (PI) controllers used in NSSS control systems for nuclear power plants (NPPs). In order to execute correct performance analysis and to support plant operation effectively for NPPs, computer codes used for performance analysis should have an ability to simulate PI controllers correctly. Therefore, it is important that PI control algorithm is correctly programmed in the computer code to describe PI controllers in hardware with high-fidelity.

However, there exist some possibilities that mismatch can occurs for simulation of PI controller according to a method by which the PI controller is converted into numerical expression. In this work, some analyses on this problem are performed and reviewed.

2. Numerical Expressions of PI Controller

The PI controller currently used in the NSSS control systems can be expressed as follows:



This PI controller can be converted into several different numerical expressions. The following numerical expressions are found in some computer codes used in the performance analysis [1,2,3]:

In following expressions, the character 'p' and 'n' commonly indicate the previous and next step value respectively.

2.1 Case 1

$$q_o = K(1+\frac{1}{\tau s})q_i$$

$$\tau s \cdot q_o = K(\tau s + 1)q_i$$

$$\tau \frac{d}{dt} q_o = K\tau \frac{d}{dt} q_i + Kq_i$$

$$\tau \frac{q_o - q_{op}}{\Delta t} = K\tau \frac{q_i - q_{ip}}{\Delta t} + Kq_i$$

$$\therefore q_o = K(q_i - q_{ip}) + K\frac{\Delta t}{\tau} q_i + q_{op}$$

2.2 Case 2

$$q_o = K(1+\frac{1}{\tau s})q_i = A + B$$

$$A = Kq_i,$$

$$B = K\frac{1}{\tau s} q_i = K\frac{1}{\tau s}\left[\frac{\tau s}{K(1+\tau s)} q_o\right] = \frac{1}{1+\tau s} q_o$$

Use forward differecne scheme,

$$B + \frac{\tau(B_n - B)}{\Delta t} = q_o \;\Rightarrow\; B_p + \frac{\tau(B - B_p)}{\Delta t} = q_{op}$$

$$B = B_p + \frac{\Delta t}{\tau}(q_{op} - B_p)$$

$$\therefore q_o = A + B = Kq_i + B_p + \frac{\Delta t}{\tau}(q_{op} - B_p)$$

2.3 Case 3

$$q_o = K(1+\frac{1}{\tau s})q_i = A + B$$

$$A = Kq_i, \quad B = K\frac{1}{\tau s} q_i$$

$$\tau \frac{d}{dt} B = Kq_i$$

$$\tau(B - B_p) = K\int q_i dt = K(\frac{q_i + q_{ip}}{2})\Delta t$$

$$B = B_p + \frac{K\Delta t}{\tau}(\frac{q_i + q_{ip}}{2})$$

$$\therefore q_o = A + B = Kq_i + B_p + \frac{K\Delta t}{\tau}(\frac{q_i + q_{ip}}{2})$$

3. Analysis for Numerical Expressions of PI Controller

The analysis for the above numerical expressions is performed through computer simulation. The CENTS code is used for simulation in this work [2]. A turbine trip event for NPP is selected as the simulation case and target control system is the pressurizer (PZR) pressure control system (PPCS). The PPCS takes the difference between PZR pressure and pressure setpoint as an input signal. This input signal is processed by PI controller logic and the resultant signal is used for PZR pressure control via heaters and spray [4]. The parameter values used in this analysis are as follows:

K = 1.0, τ = 900 sec, Δt = 0.2 sec
Pressure setpoint = 2250 psia

Through the simulation for the turbine trip event using the CENTS code, PZR pressure signal during the event is obtained. Then the difference between this obtained PZR pressure and the pressure setpoint is provided as input to the above three different numerical models for PI controller respectively. The result is shown in Figure 1.

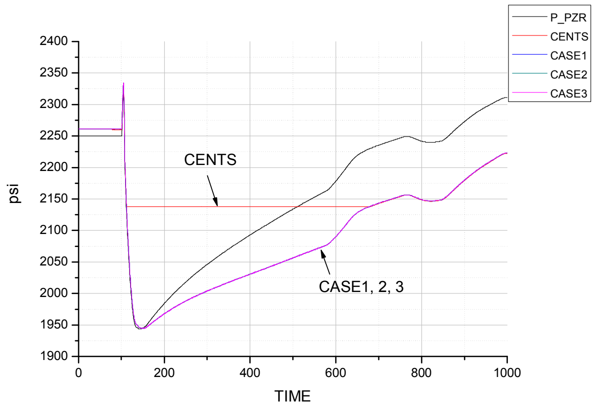


Figure 1 Outputs from various PI controllers

In this figure, the black line shows the PZR pressure and the red line indicates the output from the PI controller implemented in the CENTS codes during the turbine trip event simulation. The other three lines show the results from the above three different numerical models for PI controller. From this figure, it is shown that these three PI controller models produce identical results and perform the same function.

In practical case, however, PI controllers have a limiter that limits PI outputs within a certain band. Typically, the PI controller in the PPCS has a band from -112 to +112 psi, and from this reason, it is shown that the PI output from the CENTS code (the red line in Figure 1) is limited above 2138 psi. Therefore, the same experiment except applying the limiter is performed. The outputs q_o from the above PI models are limited within the same band (-112 to +112 psi). The result is shown in Figure 2. Different from the first experiment, these three PI controller models give different outputs each other in this experiment. The Case1, Case2, and Case3 produce the blue, green, and magenta line respectively.

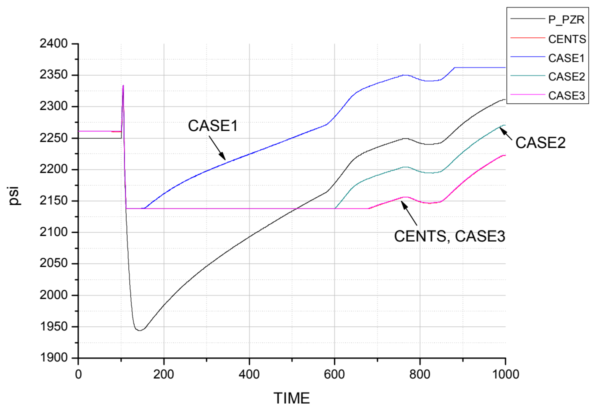


Figure 2 Outputs from various PI controllers with limiter

From these results, it is known that a mismatch can occur between the computer code result and the actual operation result of the NSSS control system in hardware when the computer code has a differently modeled PI algorithm from the actual system.

The Foxboro SPEC 200 MICRO Controller, currently used as the NSSS control system hardware, typically adopts an interacting form of PI algorithm shown in Figure 3. This form represents integral function as summation of lagged output feedback.

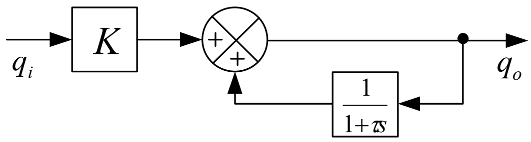


Figure 3 Interacting form of PI algorithm

According to this form, the Case 2 is the corresponding model and believed to be appropriate for the analysis computer code.

4. Conclusion and Further Study

In this work, from the analysis for some numerical models of PI control algorithm found in computer codes, it is known that there exist possibilities that mismatch can occurs between the computer code and the actual NSSS control system according to the method by which the PI controller is converted into numerical expression. Therefore synchronizing numerical PI controller model and corresponding actual control system is important, hence, adjusting the analysis computer code according to the verification on the implementation method for the actual NSSS control system hardware and its test result is required in order to execute a correct performance analysis. In addition, it can be another solution for preventing the mismatch to standardize the detailed method for implementing PI algorithm in both the analysis computer code and the NSSS control system hardware.

REFERENCES

[1] "Technical Manual for the KISPAC," KOPEC, August, 1999.
[2] "User's Manual for the CENTS Code," Westinghouse Electric Company, March, 2004.
[3] "Modeler's Manual for the CENTS Generic Control Systems," Westinghouse Electric Company, February, 2004.
[4] "Setpoint Study Korea Electric Company Units 5&6," Westinghouse Electric Company, July, 1983.