Improvement of Algorithm for Controller in Steam Bypass Control System for Preventing Spurious Control Demand

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1. Introduction

Control systems are implemented in various I&C platforms for several NPPs (Nuclear Power Plants). For this reason, the controller block in each platform is based on different methods for specific calculation and internal settings. The dynamic response of each PI (Proportional plus Integral) controller is known to be slightly different from others depending on the applied I&C platform even though the same input signal is provided [1]. Therefore, it is necessary to understand the controller's particular characteristic and verify that the controller operates normally without any defects before applying implemented control systems to an NPP.

The SBCS (Steam Bypass Control System) automatically dissipates excess energy in an NPP by regulating steam flow through the TBVs (Turbine Bypass Valves). For this purpose, the controller in this system is required to generate the related demand signals for opening the TBV if necessary using the measured steam header pressure signal as an input. During normal operation in an NPP, the TBVs should remain closed. It has been identified that the SBCS can generate unwanted control demand signal which makes it possible for the TBVs to open in specific cases, if the SBCS is implemented with the controller whose algorithm is incomplete. To solve this potential problems, we performed simulations to figure out the main reason for the spurious actuation and proposed an algorithm for the controller.

2. Functional Algorithm of Steam Bypass Control System

The SBCS releases steam through the opening of a TBV to remove excess energy in the secondary side of the plant. Since the TBV is a pneumatic type valve, high pressure air must be supplied to open it. To prevent unnecessary opening of the TBV, two 3-way solenoid valves are connected in series to control the flow of air provided to the TBV. To open one of the two solenoid valves, which is called the SBCV (Steam Bypass Control Valve), a related binary output signal should be generated in the SBCS.

Fig. 1 shows a simplified control algorithm in the SBCS Permissive channel. The measured steam header pressure signal is compared with the setpoint value to calculate an error signal e(t). Using this error signal as an input, the PI controller generates an output signal y(t) with a range of 0 to 100%. If the PI controller's output y(t) exceeds a threshold value V_{DP}, that is 1%, a binary signal z(t) is generated in the SBCS Permissive channel. This signal, which is called 'Auto Modulation Permissive', is required to open the SBCV.

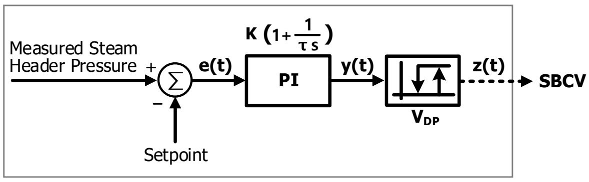

Fig. 1. Simplified functional block diagram in SBCS permissive channel

3. Potential Problem in Controllers

In a steady state without transients in an NPP, the measured steam header pressure signal normally remains lower than the setpoint. In this case, any TBVs are not allowed to open for preventing unnecessary overcooling in the steam generator. For this reason, the binary signal z(t) for opening the SBCV should not be generated. Even if the measured steam header pressure signal maintains a stable condition at a value lower than the setpoint, unwanted noise can be added to the original signal due to the uncertainty caused by corresponding sensors and analog input module, etc. As a result, the error signal e(t) can be fluctuated maintaining a negative value.

The controller in an I&C platform was found to have potential problems during the validation process. As a result of analysis by performing simulation, it was identified that this controller can cause the SBCS permissive channel to repeatedly generate unnecessary binary output signal for opening the SBCV during normal operation condition in an NPP. It can cause a negative effect on the SBCV.

Fig. 2 shows simulation results obtained assuming fluctuation of an input process variable due to the noise in a steady state. For simplicity, sinusoidal signal with small amplitude is added to a fixed negative value to reflect fluctuation in an error e(t). Using this input as a test signal, PI controller implemented in each I&C platform can be verified for detecting potential problem that can cause adverse consequences for the function of the SBCS.

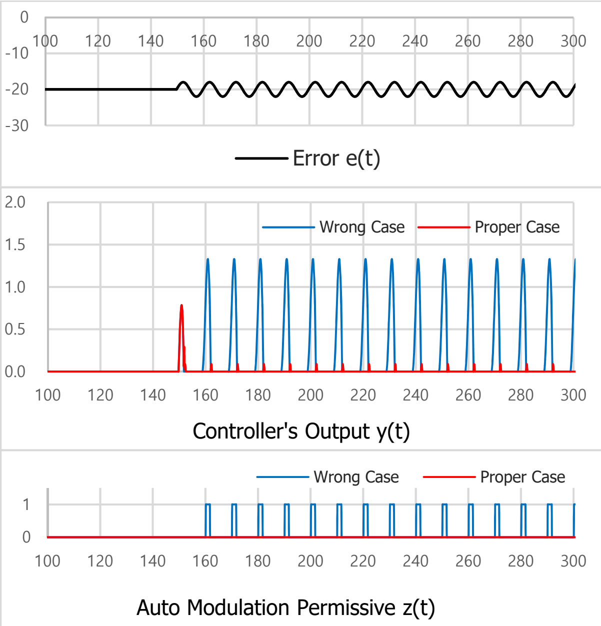

Fig. 2. Simulation results for simple condition

The specified condition and internal parameters for simulation are described in Table I. If a controller has an error, the binary output signal generated from the comparator block can have a periodic pulse signal with a constant time width as the PI controller output y(t) exceeds the value of the threshold V_{DP}. If this binary signal is provided to the SBCV, the corresponding valve will repeat periodic movement for opening. On the other hand, if the PI controller is properly implemented as intended, the effect due to the fluctuation in the measured signal can be negligible and thus the binary output signal for opening the SBCV will not be generated.

Table I: Assumption for simulation

1) Parameters in control algorithm
$Y(s) = K\left(1+\frac{1}{\tau s}\right)\cdot E(s)$ $K = 3.64, \tau = 20\ sec.$ $V_{DP} = 1\%$ (Deadband = 0.5%)
2) Error signal
$e(t) = \begin{cases} -20 & for\ t < t_c \\ -20 + A\cdot\sin\{2\pi f(t-t_c)\} & for\ t \geq t_c \end{cases}$ A = 2%, f = 0.1Hz, t_c = 150 sec.

For both cases shown in Fig. 2, each PI controller satisfies the basic calculation method to generate the output by summing the proportional term and the integral term. To implement complete controllers interfaced with operators, the other functions including operation mode change, bumpless transfer and anti-windup function are also required for improving convenience of operation and minimizing transient response due to the mode change [2]. Therefore, it is not so simple to implement controllers and thus the completeness of controllers is considered to be very important.

Table II represents an example of the inadequately implemented algorithm for controller, from which wrong case is obtained in the simulation. In this algorithm, E[n] and Y[n] denote the corresponding value at time t=n·ΔT, where ΔT is unit cycle time for discrete time based calculation in a CPU, for the nth input and output of the controller, respectively. The controller should have a clamping function to prevent the output value from exceeding the lower limit value(LOLIM) and upper limit value(HOLIM).

Table II: Incomplete algorithm for controller

```
P[n] = k*E[n];
ΔI = {k*E[n]*ΔT} / τ ;
I[n] = I[n-1] + ΔI;
Y[n] = P[n] + I[n];

if ( Y[n]>HOLIM )
        I[n] = HOLIM-P[n];
else if ( Y[n]<LOLIM )
        I[n] = LOLIM-P[n];

if (mode == MANUAL)
        I[n] = MV-P[n];

Y[n] = P[n] + I[n];
if ( Y[n] > HOLIM )
        Y[n] = HOLIM;
else if ( Y[n] < LOLIM )
        Y[n] = LOLIM;
```

To prevent spurious control demand for the SBCV as shown in Fig. 2, the controller's specific algorithm for wrong case should be corrected while satisfying all the functional requirements. The complete algorithm for controller proposed in this paper to solve potential problem is described in Table III.

Table III: Proposed algorithm for controller

```
P[n] = k*E[n];
ΔI = {k*E[n]*ΔT} / τ ;
I[n] = I[n-1] + ΔI;
Y[n] = P[n] + I[n];

if ( (Y[n]>HOLIM)&&(E[n]≥0) OR
(Y[n]<LOLIM)&&(E[n]≤0) )
        I[n] = I[n-1];

if (mode == MANUAL)
        I[n] = MV-P[n];
```

```
Y[n] = P[n] + I[n];
if ( Y[n] > HOLIM )
        Y[n] = HOLIM;
else if ( Y[n] < LOLIM )
        Y[n] = LOLIM;
```

Both algorithms in Table II and Table III satisfy the required bumpless transfer function for control mode change by tracking the controller's output value during the manual mode which is denoted by 'MV'. However, unlike the Table III, Table II has an error in the part of the algorithm for the anti-windup function. This is the main reason for the differences in the simulation results.

4. Simulation Results

Simulation was performed to verify the effectiveness of the proposed algorithm for a controller. In order to simulate the realistic situation in a steady state, the measured steam header pressure signal was assumed to have a noise. The error signal e(t) was generated by adding Gaussian distributed noise with zero mean and standard deviation of 0.1% to the negative constant value, that is -5.0%. Internal parameters for PI controller were assumed to have the same values as shown Table I. In addition, the unit cycle time for CPU calculation was assumed to be 0.1 seconds.

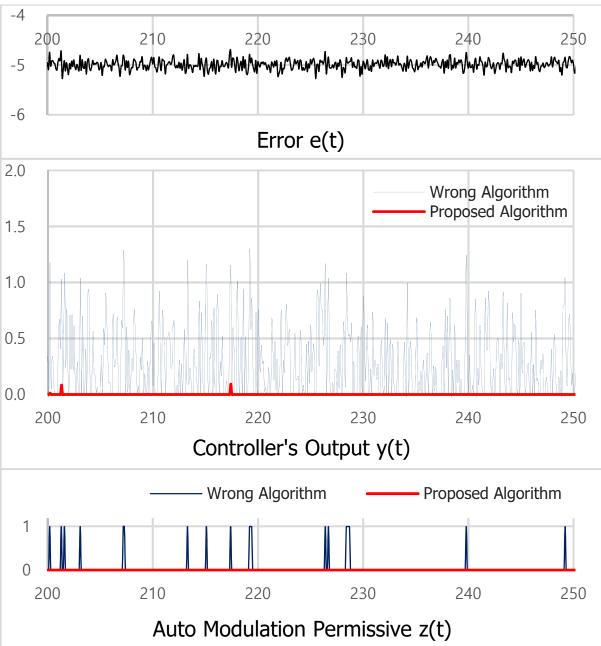

Fig. 3. simulation results obtained according to the practical input applied for both cases

Fig. 3 shows the simulation results for the functional algorithm of the SBCS. Even though the same input signal is applied, the controller's output signal is heavily affected by noise if there is a potential problem in the controller's algorithm. Accordingly, the binary output signal for opening the SBCV will be generated very frequently as the controller's output y(t) exceeds the threshold VDT (=1.0%). If this inadequate controller's algorithm is used to implement the SBCS in a plant, it can cause mechanical damage to the SBCV. Moreover, if the SBCS main channel fails to operate normally and thus generates spurious output signals, it can cause the corresponding TBVs to open improperly.

If the proposed algorithm is applied to the controller, its resulting output signal y(t) is shown to be close to zero. Since this signal maintains a value less than the threshold, unwanted control demand signal for the SBCV will not be generated. Therefore, applying the proposed algorithm to the SBCS will be consistent with the design intent, since it can prevent a situation in which unnecessary operation of the SBCV is caused during normal operation condition in an NPP.

5. Conclusions

In order to check whether there is a hidden problem in a controller block, a test simulation assuming a specific situation was performed. If a problem is revealed through this test, the proposed algorithm for the controller can be a good solution as the simulation results show the effectiveness of this algorithm. In addition, the proposed algorithm satisfies several functional requirements for the controller interfaced with operators. It is expected that the reliability and completeness of the NSSS control systems in a plant can be improved by utilizing the functional test methodology and solution for controllers described in this paper.

REFERENCES

[1] Myunghoon Ahn, Juyoung Kim, Hyunho Choi, Hyeongsoon Yim, "Analysis on Dynamic Response of PI Controllers Applied in Nuclear Power Plants", Transactions of the Korean Nuclear Society Autumn Meeting, October 29-30, 2015

[2] Y Peng, D Vrancic and R Hanus, "Anti-Windup, Bumpless, and Conditioned Transfer Techniques for PID Controllers," IEEE Control Systems, 16.4 (1996): 48-57.