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# Analysis and Improvement of Control Algorithm for Operation Mode Transition due to Input Channel Trouble in Control Systems

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## 1. Introduction

The PI (Proportional plus Integral) controller, which is the essential functional block in control systems, can automatically perform the stable control of an important plant process while reducing the steady state error and improving the transient response. However, if the received input PV (Process Variable) is not normal due to input channel trouble, it will be difficult to control the system automatically. For this reason, many control systems are implemented to change the operation mode from automatic to manual mode in the PI controller when the failed input PV is detected. However, this operation of the control system may cause an adverse effect on a plant in some cases. To find an appropriate means for preventing an unexpected situation in the case of input channel trouble, we performed analysis on the effects for overall cases.

## 2. Implemented Control System

Fig. 1 shows the original closed-loop block diagram implemented in the NSSS (Nuclear Steam Supply System) control systems. The PV, the input of the NSSS control system, is connected to the 'QUAL' block which generates 'True (1)' as an output if it has any trouble such as sensor failure, input module failure, out-of-range, etc. When the PV has trouble, the controller is changed into the manual mode during which the operator can change the manual output to control the corresponding component. During the normal operation, the controller is in automatic mode and thus calculates the appropriate PI controller output by using the PV and the SP (Setpoint). In the implemented system, the *output tracking* function is enabled in the controller so that the mode change can be possible without any bump in the controller output [1].

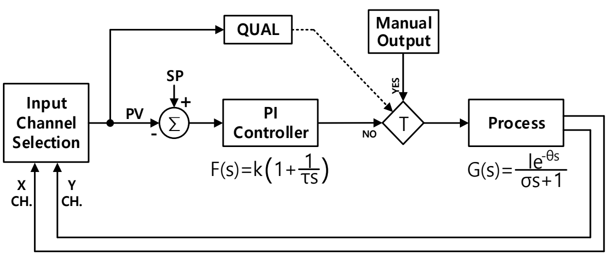


Fig. 1. Functional block diagram for the implemented closed loop system with a plant process model

## 3. Analysis

The causes that result in a bad quality in a PV can be categorized as the following two cases.

- Case 1: Actual failure in the related hardware
- Case 2: Out-of-range event due to process transient

The 'Case 1' means the actual hardware failure, which includes failures in the related sensors, input modules, and so on. A bad quality in the PV will be maintained until the hardware is repaired. On the other hand, the 'Case 2' does not mean the hardware failure in the input channel. Therefore, the value of the input sensor signal reflects the actual process in the plant. Due to a process transient according to a disturbance or an operation mode change, the input signal can exceed the pre-defined range used for detection of a bad quality which is slightly wider than the span of the input sensor signal. In this case, the quality of the input PV is considered to be bad. As the PV can be recovered to the normal range in a certain time, the 'Case 2' is considered to be temporary case.

### *3.1 Case 1*

In most of non-safety NSSS control systems, for each PV there are two input sensors ('X' and 'Y' channel) for redundancy. The PV, which is the output of the channel selection algorithm, is the average of signals from two input channels in normal situation.

Let's assume that a hardware failure occurs in only one of two input channels. In this case, the channel selection algorithm selects the remaining normal input channel. As the PV is still in good quality despite this event, the corresponding control system can perform the normal operation while maintaining the automatic mode.

If the remaining normal input channel also has a trouble in the related hardware even though its probability is extremely low, it will eventually cause a bad quality in the PV. During the manual mode in the PI controller, the operator cannot adequately adjust the manual output to control the PV, because the actual process input is not monitored any longer. Even though the PI controller maintains the automatic mode for this case, calculations in the control algorithm will be performed based on the inaccurate input PV. It can cause inadvertent results in the NSSS. In conclusion, when both of input channels are in trouble, it is difficult to properly perform the process control in either manual or automatic mode in the PI controller.

*3.2 Case 2*

When the out-of-range event occurs as the values of the measured input channels exceed a given range (e.g. -5% ~ 105%), the PV is considered as a bad quality even though there is no hardware failure in the related input channels. This event occurs almost simultaneously at both input channels, because the sensor in each channel can normally measure the actual plant process.

If the operation mode in the PI controller is changed from automatic mode to manual mode upon detection of 'Case 2', the control signal will be fixed to a certain value, which is the last value of the PI controller output just before the mode transition, until the operator directly changes the manual output. Before the operator takes a proper action, the feedback control reflecting the current input PV is not performed. Therefore, it is very important for the operator to take prompt actions with precise control to recover the transient in the plant process after PI controller is changed into the manual mode. It can be a big burden for the operators.

Let's assume that the controller maintains the automatic mode regardless of the out-of-range event in the PV. Even though the PV exceeds the threshold, the modified value (PV'), which is saturated to the High Threshold '$H_{th}$' or the Low Threshold '$L_{th}$' as the following equation, will be used effectively as an input of the PI controller.

$$PV' = \begin{cases} H_{th}, & \text{if } PV > H_{th} \\ PV, & \text{if } L_{th} \le PV \le H_{th} \\ L_{th}, & \text{if } PV < L_{th} \end{cases} \tag{1}$$

The control system will automatically perform the feedback control to mitigate the transient without the operator's action. Unlike the manual mode, the automatic mode makes it possible to effectively control the process variable within the normal range in a short time without interruption while maintaining stability.

## 4. Simulation Results

For the case 1, performing the simulations to determine which operation mode in the PI controller is more appropriate is not necessary, because it is not possible to control a system in the absence of the normal input signal. On the other hand, for the case 2, the input channel signals reflecting the actual process are continuously provided to a control system. For this reason, we performed simulation for the case 2 to demonstrate the difference in the results according to the operation modes upon the out-of-range event in the PV.

For the simulation, we considered the process in the plant as the FOPDT (First Order Plus Dead Time) system, whose transfer function is denoted as the following equation [2].

$$G(s) = \frac{le^{-\theta s}}{\sigma s + 1} \tag{2}$$

For simplicity the process was assumed to be as follows with the dead time $\theta$=0.

$$G(s) = \frac{2}{200s + 1} \tag{3}$$

For this process, the suitable parameters in the PI controller, whose transfer function F(s) is shown in Fig. 1, were assumed as follows: proportional gain k=5 and integral time constant $\tau$=20 seconds. In addition, let's assume that due to a process transient the out-of-range event already occurs and the initial values at time t=0 for the PV and the controller output were -10% and 60%, respectively. In this simulation, the value of the SP was fixed to 50%.

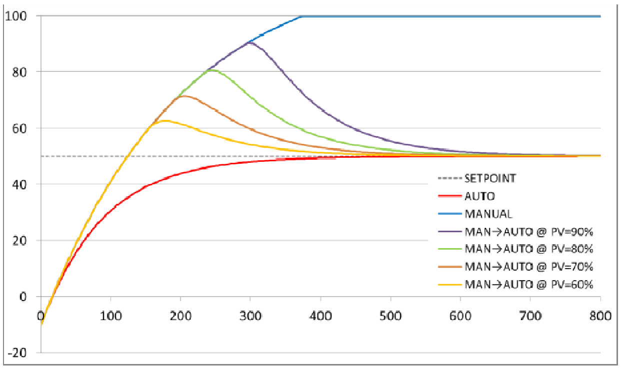


Fig. 2. The corresponding process variables according to different operation modes in the PI controller

Fig. 2 and Fig. 3 show the simulation results according to the different operation modes in the controller for the PV and the controller output signals, respectively. As shown in Fig. 2, the PV can deviate from the SP as an operator's action is delayed since the controller was changed to the manual mode at time t=0 in the original system. If the operator changes the operation mode into the automatic mode, the system will reach a steady state through the feedback control algorithm. Although the simulation results do not include the response according to adjustment of the manual output by an operator during the manual mode, it may be difficult for an operator to directly control the related components through immediate and elaborate way as in the automatic mode. Furthermore, the manual operation requires the operator's continuous action.

On the other hand, if the controller maintains the automatic mode regardless of the out-of-range event as the proposed scheme, the PV approaches the SP in less time than the other cases with the stable dynamic response as shown in Fig. 2.

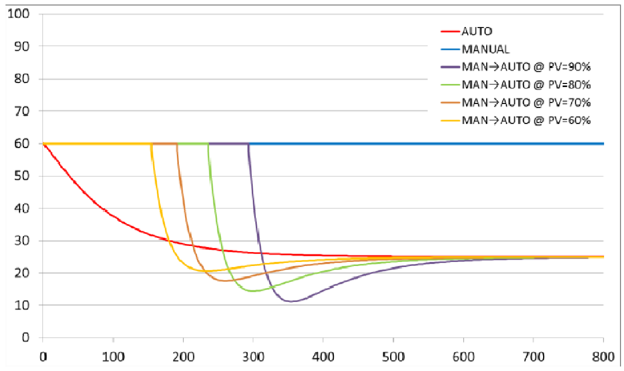

Fig. 3. The corresponding controller output according to different operation modes in the PI controller

The controller output signals for several cases are shown in Fig. 3. If the PI controller is in automatic mode for all the time, the control signal varies as the change of the input PV is continuously reflected in the control algorithm. In the other cases, since the controller changes into the manual mode at t=0, the control signal is fixed at the last PI controller output and thus the feedback control is not performed anymore until the operator takes an action such as the operation mode change as shown in Fig. 3.

## 5. Conclusions

As a result of analysis and simulations for the controller's operation modes in all the cases of input channel trouble, we discovered that it is more appropriate to maintain the automatic mode despite the bad quality in the PV. Therefore, we improved the control system algorithm reflecting the analysis results for the operator's convenience and the stability of a control system.

## REFERENCES

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[2] Visioli, Antonio, "Modified anti-windup scheme for PID controllers," IEE Proceedings-Control Theory and Applications, 150.1 (2003): 49-54