Design and Implementation of Supervisory Control and Data Acquisition Based Manufacturing System Using PID Control

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Abstract- In this research, the main theme is the system integration of Supervisory Control and Data Acquisition (SCADA) Based Mini Factory Design Using PID Control. The integrated system is composed of the master terminal unit (MTU) and the remote terminal units (RTUs). The main function of master terminal unit is acquired data from RTUs within the region, log and display this data on a local operator station, pass data back to the master station, and pass on control requests from the master station to the RTUs in its region. The remote terminal unit means PLC, DCS or IED is located at a remote location in industrial automation, which is composed of the actuator systems and the sensory systems. The communication system uses industrial ethernet communication system, which combines the master terminal unit with the remote terminal units. To integrate both systems, the signal classification, baud rate of communication system and system characteristics considered PID control is designed with signal and measurement theory. This research analyzes the stability state from remote terminal units (RTUs) to field elements of manufacturing process. Moreover, the simulation results of PID controller are shown with MATLAB simulink**.**

Index Terms-PID control, SCADA, Master terminal units (MTUs), Remote terminal units (RTUs), Mini-factory Design.

I. INTRODUCTION

This computer-based supervisory control and data acquisition (SCADA) systems have evolved, from standalone, compartmentalized operations into networked architectures that communicate across large distances. In addition, their implementations have migrated from custom hardware and software to standard hardware and software platforms. Some of the characteristics, performance requirements, and protocols of SCADA system components require adapting information-system security methods in industrial settings. Supervisory control and data acquisition (SCADA) systems are vital components of most nations' critical infrastructures. They control pipelines, water and transportation systems, utilities, refineries, chemical plants, and a wide variety of manufacturing operations. SCADA provides management with real-time data on production operations; implements more efficient control paradigms, improve plant and personnel safety, and reduce costs of operation. These benefits are made possible by the use of standard hardware and software in SCADA systems combined with improved communication protocols and increased connectivity to outside networks, including the Internet. However, these benefits are acquired at the price of increased vulnerability to attacks or erroneous actions from a variety of external and internal sources.

In this research, the system presents how to control the unstable spare parts batch process industry by PID controller. The stability analysis of Remote Terminal Units (RTUs) could be designed by applying the ideas of that PID control techniques. This research used the MATLAB PID commands for simulation results. According to the simulation results, the steady state error will be zero at infinite time. By changing the simulation parameters from this research, it could analyze difference applications for other control system to be stable. After applying the PID controller, the condition of that factory will be reached to the stability state.

II. SCADA BASED MINI-FACTORY DESIGN
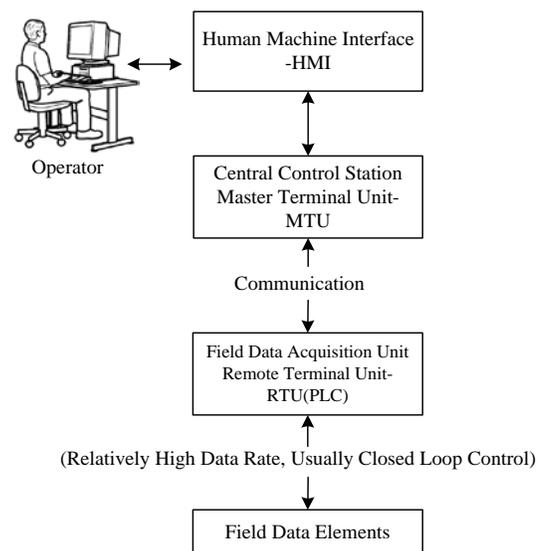
A. Design Block Diagram

Fig.1. SCADA System Architecture

The SCADA system architecture is shown in Fig.1. This system consists of three levels to control the field elements from the operator. The first level is operator level, the second level is communication level and the third level is field level. The stability techniques are based on the PID control for master terminal units (MTUs).

B. Second-Order Process and a PID Controller

In the processing industry, PID controllers play a crucial role in keeping our plants running – virtually everything from simply filling up a storage tank to complex Mini-Factory. PID control is the most commonly used strategy for programmable controllers in the industry. PID Controllers have been in use for many years, due to their ease of use and ability to effectively control a wide range of plants. In recent years there has been substantial interest in auto-tuners for PID controllers. PID control is a widely used in the most of the industrial automation process because of its remarkable efficiency, simplicity of implementation and broad applicability. The PID control algorithm is a three-term linear control strategy that uses proportional control as its major control term, integral action to largely remove steady state error, and derivative control to add stability to a loop and thus facilitating the use of higher proportional action.
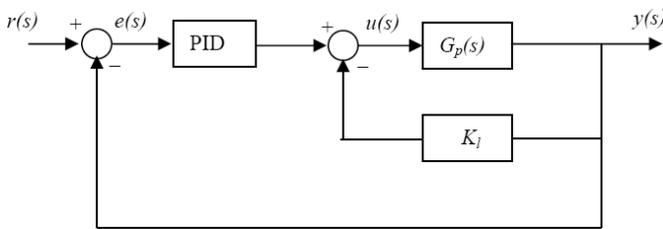

Fig.2. Block Diagram of Two Loop Controller

C. Integrating Process

For controller design purpose, we used the following simple integrating process:

$$G_p(s)=\frac{K}{(\tau s-1)}e^{-Ls} \tag{1}$$

With proportional controller in the inner feedback loop, the internal closed-loop transfer function $G_l(s)$ can be obtained as

$$G_l(s)=\frac{G_p(s)}{1+K_lG_p(s)}=\frac{Ke^{-Ls}}{\tau s-1+KK_le^{-Ls}} \tag{2}$$

By using a Taylor series expansion, the time delay term in the denominator of equation (2) can be approximated by

$$e^{-Ls}\cong1-Ls+0.5L^2s^2 \tag{3}$$

By substituting

$$G_l(s)\cong G'_p(s)$$

$$=\frac{Ke^{-Ls}}{0.5KK_lL^2s^2+(\tau-KK_lL)s+KK_l-1} \tag{4}$$

Here, $G'_p(s)$ denotes the second-order plus time-delay model obtained from the Taylor series expansion method. Since the characteristic equation of $G'_p(s)'$ should have negative poles to be stable, the following condition must be satisfied from the Routh-Hurwitz stability criterion

$$K_{min}=\frac{1}{K}<K_l<\frac{\tau}{LK}=K_{max} \tag{5}$$

For optimum disturbance rejection, it was proposed as:

$$K_l=\sqrt{K_{min}K_{max}}=\frac{1}{K}\sqrt{\frac{\tau}{L}} \tag{6}$$

Then

$$G_p(s)=\frac{\frac{K\sqrt{L}}{(\sqrt{\tau}-\sqrt{L})}e^{-Ls}}{\frac{0.5L^2\sqrt{\tau}}{(\sqrt{\tau}-\sqrt{L})}s^2+\frac{(\tau\sqrt{L}-L\sqrt{\tau})}{(\sqrt{\tau}-\sqrt{L})}s+1} \tag{7}$$

The design method proposed can be directly used to design controller

$$b_0=\frac{K\sqrt{L}}{(\sqrt{\tau}-\sqrt{L})}$$

$$a_2=\frac{0.5L^2\sqrt{\tau}}{(\sqrt{\tau}-\sqrt{L})}$$

$$a_1=\frac{(\tau\sqrt{L}-L\sqrt{\tau})}{(\sqrt{\tau}-\sqrt{L})} \tag{8}$$

$$\begin{bmatrix}K_p\\K_i\\K_d\end{bmatrix}=\frac{\pi}{2A_mKL\sqrt{L}}\begin{bmatrix}\frac{(\tau\sqrt{L}-L\sqrt{\tau})}{(\sqrt{\tau}-\sqrt{L})}\\0.5L^2\sqrt{\tau}\end{bmatrix} \tag{9}$$

From Fig.2, $e(s)=r(s)-y(s)$, the process input $u(s)$ can be written as

$$u(s)=\left(K_p+\frac{K_i}{s}+K_ds\right)[r(s)-y(s)]-K_ly(s)$$

$$=\left(K_p+K_l\right)\left[\frac{K_p}{K_p+K_l}r(s)-y(s)\right]+\left(\frac{K_i}{s}+K_ds\right)e(s) \tag{10}$$

Let $b=\frac{K_p}{K_p+K_l}$ and $K'_p=K_p+K_l$ we can be obtained $u(s)$ in the following form:

$$u(s)=K'_p\left(b\times r(s)-y(s)\right)+\left(\frac{K_i}{s}+K_ds\right)e(s) \tag{11}$$

The net result of inner feedback loop is the equation (11) which is the two-degree of freedom PID controller, where K'_p, K_i, K_d and set-point weighting are PID settings as shown in Fig.3.

The effect of K_l is reflected in the PID controller design, we can ignore the inner feedback loop and directly design PID controllers for integrating or unstable time delay processes by equation (9).
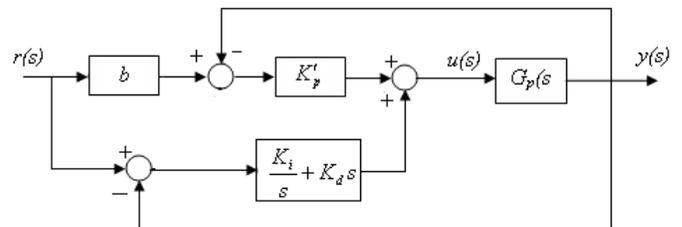

Fig.3. Implementation of PID Control for Integrating and Unstable Processes

D. Research Example

The integrating process transfer function is as follows:

$$G_p(s)=\frac{e^{-0.2s}}{s(s+1)} \tag{12}$$

The control performance of the proposed method is compared with PID tuning methods for integrating processes. PID controller settings for each method are listed in Table .1.

Table.1. PID Controller Setting for Research Example

Gain and Phase Margin Method	
K_p'	3.0994
K_i	2.618
K_d	2.6704
b	0.6768

III. FLOW CHART OF PID CONTROLLER FOR MANUFACTURING SYSTEM

```
            Start
              ↓
   System Parameters and
      Simulation Time
              ↓
     Initial Error Value
              ↓
   Two Errors Derivative
          Value
              ↓
      Increase Time, dt
              ↓
   Calculate Error1 and
         Error2
              ↓
     Initial Condition
              ↓
   Calculate Time and
  Response with ODE 45
              ↓
    Calculate the yp
    (PID response)
              ↓
    Response of the PID
        Controller
              ↓
            End
```
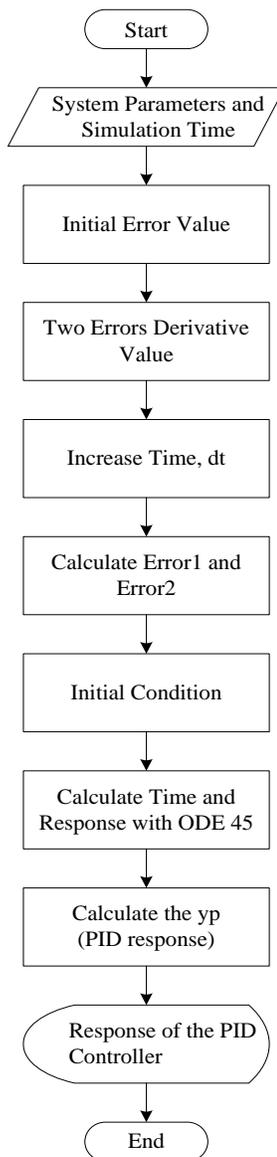
Fig.4. Flow Chart of PID Controller for Manufacturing System

This flow chart explains the simulation of PID controller for manufacturing system. It includes start and stop, simulation parameters and time, initial error value, two error derivative

value, calculate time response ODE and display a response curve for the PID controller. And then simulation parameters for PID controller are shown in Table.2.

Table.2. Simulation Parameters for PID Controller

Proportional Gain, K_p	Integral Gain, K_i	Derivative Gain, K_d	Input Reference	Transfer Function
0.5	0.05	3	10	1000
1.0	0.5	3	10	1000
1.5	1.5	1.5	10	1000
2.0	1.0	2.0	10	1000
2.5	2.0	2.5	10	1000
3.0	2.5	2.5	10	1000
3.0994	2.618	2.6704	10	1000

IV. SIMULATION RESULTS OF PID CONTROL SYSTEM

In this research, "PID" is an acronym for "proportional, integral, and derivative." A PID controller is a controller that includes elements with those three functions. In the literature on PID controllers, acronyms are also used at the element level: the proportional element is referred to as the "P element," the integral element as the "I element," and the derivative element as the "D element." An investigation performed in 1989 in Japan indicated that more than 90% of the controllers used in process industries are PID controllers and advanced versions of the PID controller.

The normal manufacturing system could not be stable for running condition. But the PID controller for stable system is added to the unstable system for manufacturing system. The present manufacturing system is process industry. The following results are shown in bellow with various conditions. In this page, it includes ten time steps and eight magnitude steps. The simulation results are depended on three gains that are Proportional gain (K_p), Integral gain (K_i) and Derivative gain (K_d) The simulation parameters are given in Table 4.2. In this research, the experimental results could be displayed with three kinds of gain for the PID controller. These gain results will be appreciated for manufacturing processes used PID control.
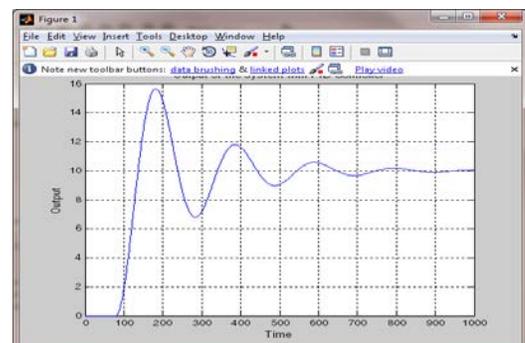

Fig.5. Simulation Result for Parameter One from Table.2.

The simulation result for parameter one shown in Figure 5. In this result, the system parameters used to $K_p=0.5$, $K_i=0.05$, $K_d=3$ and $T_f=1000$. The result has high overshoot and undershoots between time 100 and 200. Then, this result approaches to stable stability state about 900 seconds.
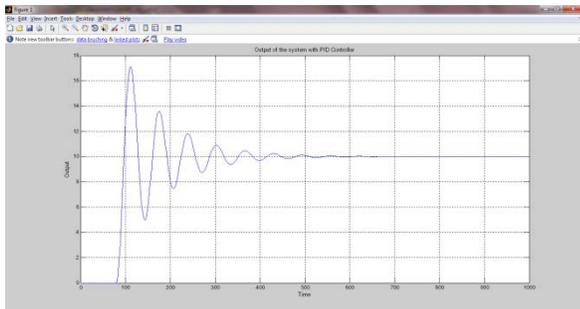

Fig.6. Simulation Result for Parameter Two from Table.2.

The simulation result for parameter two shown in Figure 6. In this result, the system parameters is $K_p=1$, $K_i=0.5$, $K_d=3$ and $T_f=1000$. This result had high overshoot and undershoots between 100 and 150 time steps. Then the system approaches to the stability state about t=500 seconds. Therefore, the stability condition depends on three gains of PID controller.
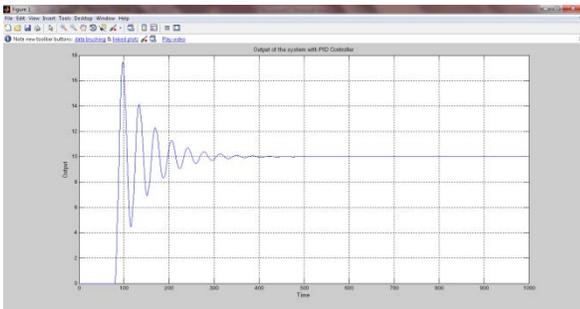

Fig.7. Simulation Result for Parameter Three from Table.2.

The simulation result for parameter three shown in Figure 7. In this result, the system parameters is $K_p=1.5$, $K_i=1.5$, $K_d=1.5$ and $T_f=1000$. The result had high overshoot between 80 and 120 time steps. Then the system approaches to the stability state about t=400 seconds. Therefore, the stability condition depends on three gains of PID controller.
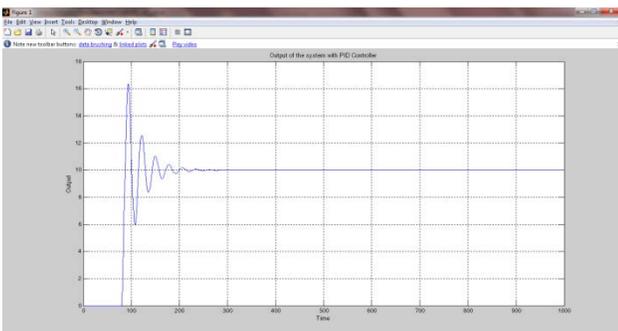

Fig.8. Simulation Result for Parameter Six from Table.2.

The simulation result for parameter six shown in Figure 8. In this result, the system parameters used to $K_p=3$, $K_i=2.5$, $K_d=2.5$ and

$T_f=1000$. The result had zero values about between 0 and 80 time steps. Because the angle use at this is 80 degree. Then, it had high overshoot and high undershoots about between time 80 and 140. Then, system had stable about T=220 seconds. But, the transfer function used 1000 at this result.
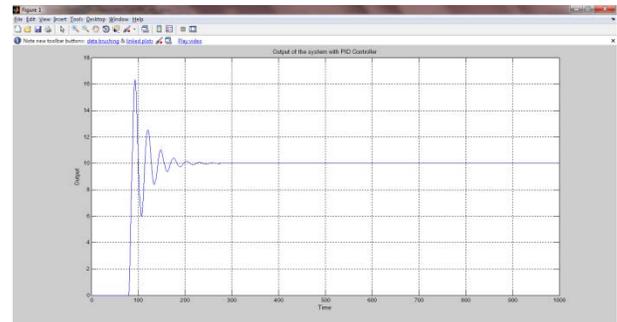

Fig.9. Simulation Result for Parameter Seven from Table.2.

The above simulation parameter used $K_p=3.0994$, $K_i=2.618$, $K_d=2.6704$ and transfer function $T_f=1000$ seconds. The result is approached to stability state about T=210 seconds. So the latest result has the most stability condition than any other parameters from this research. Therefore, the research reaches the stability state during the less transfer function time of the system.

V. CONCLUSION

In this paper the system has presented how to control the unstable spare parts batch process industry by the PID controller. The stability analysis of remote terminal units (RTUs) could be designed by applying the ideas of that PID control techniques. The author used the MATLAB PID commands for simulation results. According to the simulation results, the steady state error will be zero at infinite time. By changing the simulation parameters from this research, different applications for other control system could be analyzed to be stable.

This system is developed to control the stable state of the system such as manufacturing system, waste water system and etc. Using this PID control system, it is intended to become stability condition from the process. The advantage of this system is low cost, less worker, precise the manufacturing process and save the time. This research explains how to control unstable spare parts batch process industry by PID controller. The stability analysis of Remote Terminal Units (RTUs) could be designed by applying the ideas of that PID control techniques. Implementation of supervisory control and data acquisition based manufacturing system used MATLAB programming for this system. According to the simulation results, the steady state error will be zero at infinite time. After applying the PID controller, the condition of that factory will be reached to the stability state. This system will be applied for various industrial processes.

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