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## The Study and Development of SCADA System Using Artificial Intelligence Technique

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### ABSTRACT

*This paper concerned the study and development of Supervisory Control and Data Acquisition (SCADA) system for the monitoring of PID process control, in view of the fuzziness and the uncertainty of SCADA in fault-diagnosis and parameter-error. The tested model, in this case, was meant to be an educational-type boiler system, temperature and level sensors attached to the boiler. Involved in the development of a digital-data-transfer technique between a PC and PLCs, using Ethernet (TCP/IP Protocol) in communication. The SCADA system provided the procedure for monitoring and improving the uncertainty of the control loop via recalibrating the parameters. The uncertainty of the control loop was normally caused by the changes of system dynamics such as inrush in/out flow of the fluid or the rapid changes of setting temperature. Although many PLCs have tuning procedures for these parameters adjustment, PLCs still need someone to tell them when to tune. The PC acquired PLCs' data line analyzing the logic relations of each signal concurrently. In addition, increase the efficiency and precision of control system for PLCs has not a fuzzy logic module.*

### 1. INTRODUCTION

The control of large, complicated engineered systems such as electric power grids, transportation system, and manufacturing systems is increasingly being accomplished using sophisticated supervisory control and data acquisition (SCADA) systems. Modern SCADA systems typically possess a hierarchical structure characterized by continuous dynamics at the lower levels and logical decision-making at the upper levels. To a large degree it is this combination of continuous and logical components which makes possible the successful control of complex and/or poorly understood plants; however, this "hybrid" structure also makes the analysis and synthesis of SCADA systems very challenging.

The security of SCADA systems is recognized to be a critical national (and international) concern. An important component of any comprehensive SCADA system security program is the accurately and reliably assess the capability to accurately and reliably assess the vulnerability of these systems to various types of failures. It can be demonstrated that in order to assess vulnerability in a rigorous and complete manner it is necessary to be able to develop an accurate quantitative model for the system using measured data [1]. It should be noted that this capability is also essential for a wide range of other applications. In many applications it is often reasonable to assume that the basic structural features of the system model can be determined a priori, for instance from considerations regarding the relevant physics or the underlying supervisor logic. Once this basic structural form has been deduced the task of constructing a mathematical representation of the system becomes one of parametric system identification, in which the values of (suitably defined) parameters in the model are determined using measurements of inputs and outputs.

Very few results have been reported to date on the identification of SCADA systems using measured data. As indicated above, successful system identification requires the development of an appropriate (parameterized) model for the system. We seek a modeling framework which is general enough to be applicable to a wide range of SCADA systems and yet retains enough structure to reflect the important properties inherent in the system and to permit meaningful analysis to be conducted using the resulting model. One criterion any suitable framework must meet is the ability to display the rich dynamical behavior that results from the interaction of the continuous and logical components of the system. Additionally, it is desirable to adopt a modeling framework which permits prior knowledge regarding the system structure to be conveniently incorporated. Once an appropriate parameterized model is obtained, the task of determining the parameter values can then be undertaken.

Nowadays the SCADA system has been popularly used in Thailand. It is used not only in the medium-sized industries but also in the large-sized industries. The SCADA system which can reduce the labor problem is performed by using the monitor system and control to work together with the automatic machine system. The controller can manage from the center point via the remote terminal unit system (Multi-drip: 2 wire or wireless) to the automatic controlling equipment or PLC. This can lessen the inexperience-controlling problem. The information will be back up or built as a database, which is easy to use and check. Many software companies and the automatic controlling system companies have collaborate to develop the SCADA system to have more potential use. In addition, these companies have put some other equipment into the SCADA system which the aim is to increase the controlling ability.

In this paper, we bring Fuzzy system to find PID parameters used to control temperature of boiler model. This technique can get the wanted temperature rapidly by using Visual Basic 6 to create SCADA system model and Artificial Intelligence typed Fuzzy to design the feedback compensated value [4], [6] and then find the output value of Fuzzy control following the rule called "Parallel Distributed Compensation or PDC" [2], [4] via Non Fuzzy module PLC transferring data by Ethernet (TCP/IP) protocol which is the wide transmission standard and easy to develop.

## 2. EQUIPMENT AND METHOD

The communication of PLC Omron uses Complete V2.0 program, Active X component, and Visual Basic 6. Its protocol received and sent the information is shown as Fig. 1.

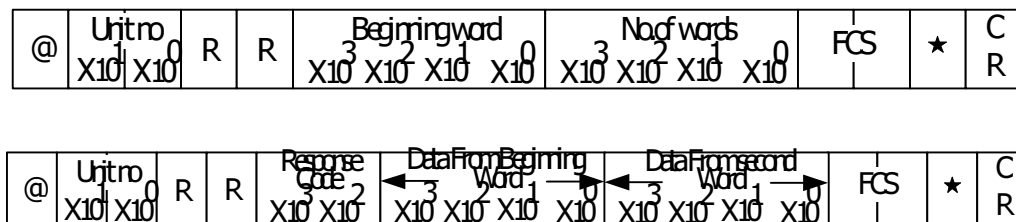


Fig.1 The form of sending and receiving the information between PLC and PC

Fig.1 is the communication between PLC and PC in the form of FINS Command developed by Omron Electronic Company. The equipments used to control temperature transfer information by digital transmission via RS-485 typed Half Duplex used CompoWay/F protocol. The frame of transmission is shown in Fig. 2.

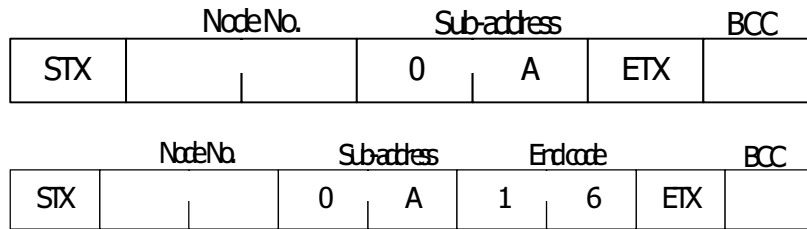


Fig. 2 The form of sending and receiving the information between PLC and Equipment controlled temperature

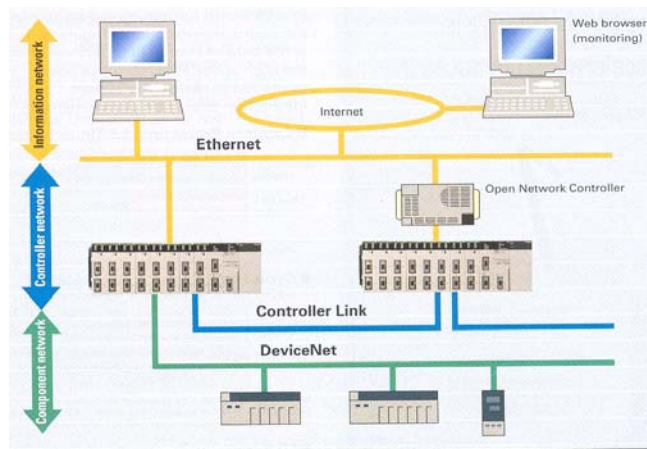


Fig. 3 The network system of PLC Omron model CS1G and Computer

The Fig. 3 is the collaboration between Programmable Logic Controller model CS1G and Personal Computer typed Ethernet (TCP/IP) which has speed rate 10 Mbps and suitable IP address. The FINS GATEWAY is the connection between them and Visual Basic 6 is used to develop the controlling and monitoring system.

The concept of writing Visual Basic 6 uses the Component ActiveX Compoete together. The general structure of control system used as reference to write SCADA software is in Fig. 4.

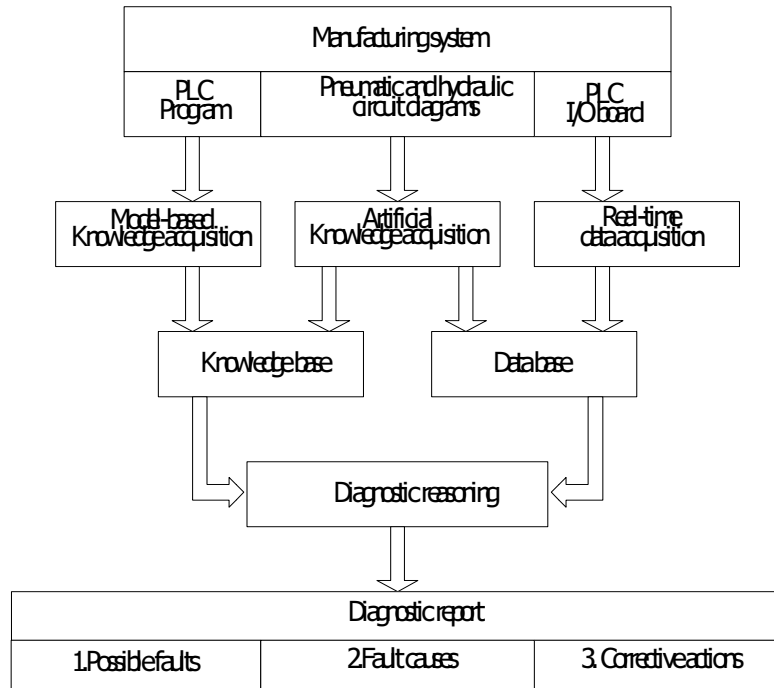


Fig. 4 The structure of general SCADA

Using SCADA system with the boiler system model, Fuzzy logic is brought to control PID parameters to increase stability of control system. Takagi and Sugeno Fuzzy model show the controlling state and can write the Fuzzy rule below:

$$L^i : IF x_1(k) \text{ is } M_{i1} \dots \text{ and } x_n(k) \text{ is } M_{in} \\ THEN x(k+1) = A_i x(k) + B_i u(k)$$

- where,  $x(k) = [x_1(k), x_2(k), \dots, x_n(k)]^T$ ,
- $u(k) = [u_1(k), u_2(k), \dots, u_n(k)]^T$ ,
- $L_i =$  Fuzzy rule  $i$ ;  $i = 1, 2, \dots, n$ ,
- $n =$  all Fuzzy control rules,
- $M_{in} =$  member rule  $i$  in term set  $n$ , and
- $x(k+1) = A_i x(k) + B_i u(k)$ ; the out put of Fuzzy rule order  $i$ .

The final output value of Fuzzy system is

$$x(k+1) = \frac{\sum_{i=1}^r w_i(k) \{A_i x(k) + B_i u(k)\}}{\sum_{i=1}^r w_i(k)} \tag{1}$$

where,  $w_i(k) = \prod_{j=1}^n M_{ij}(x_j(k))$ ,  
 $w_i(k) =$  Gravity of rule  $i$ , and  
 $M_{ij}(x_j(k)) =$  the member rule  $i$  in term set  $j$ .

When  $j = 1, 2, \dots, n$  showing term set of input.

$$A_i = \begin{bmatrix} a_1^i & a_2^i & \dots & a_{n-1}^i & a_n^i \\ 1 & 0 & \dots & 0 & 0 \\ 0 & 0 & \dots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \dots & 0 & 1 \end{bmatrix} \quad B_i = \begin{bmatrix} 1 \\ 0 \\ \vdots \\ 0 \\ 0 \end{bmatrix}$$

$A_i$  is the showing state matrix rule  $i$  and  $B_i$  is the input matrix rule  $i$  when open loop of control system in Eq. (1). The output of Fuzzy rule is

$$x(k+1) = \frac{\sum_{i=1}^r w_i(k) A_i x(k)}{\sum_{i=1}^r w_i(k)} \tag{2}$$

$$\sum_{i=1}^r w_i(k) > 1,$$

$$w_i(k) \geq 1 \quad i = 1, 2, \dots, r$$

### 3. PARALLEL DISTRIBUTED COMPENSATION

The concept of PDC designs Fuzzy control in order to compensate each rule of Fuzzy system in Eq. (1)

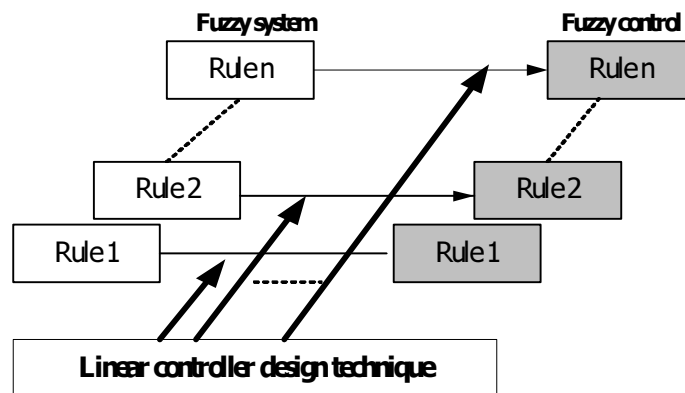


Fig. 5 Parallel Distributed Compensation

Feedback value of Fuzzy  $u(k) = -F_i x(k)$  in term  $F_i x(k)$  can find from the feedback compensation value of linear control system. Feedback Fuzzy control value of each rule can write by:

$$R^i : \text{IF } x_1(k) \text{ is } M_{i1} \dots \text{and } x_n(k) \text{ is } M_{in} \\ \text{THEN } u(k) = -F_i x(k)$$

If  $i = 1, 2, \dots, r$ , Then the output of Fuzzy control is

$$u(k) = \frac{-\sum_{i=1}^r w_i(k) F_i x(k)}{\sum_{i=1}^r w_i(k)} \quad (3)$$

Bring Eq. (3) adding up to Eq. (1) then

$$x(k+1) = \frac{\sum_{i=1}^r \sum_{j=1}^r w_i(k) w_j(k) \{A_i - B_i F_j\} x(k)}{\sum_{i=1}^r \sum_{j=1}^r w_i(k) w_j(k)} \quad (4)$$

### 3.1 Theory 1

The equilibrium point of Fuzzy control in Eq. (4) is the stability based asymptote. If we can prove that matrix P then the positive definite can find by equation.

$$\{A_i - B_i F_j\}^T P \{A_i - B_i\} - P < 0 \quad (5)$$

where,

$$w_i(k) \cdot w_j(k) \neq 0, \forall k, \quad i, j = 1, 2, \dots, r$$

Therefore, the system in Eq. (4) can revise as:

$$x(k+1) = \frac{1}{W} \left[ \sum_{j=1}^r w_i(k) w_j(k) \{A_i - B_i F_j\} x(k) + 2 \sum_{i < j} w_i(k) w_j(k) G_{ij} x(k) \right] \quad (6)$$

$$G_{ij} = \frac{\{A_i - B_i F_j\} + \{A_j - B_j F_i\}}{2} \quad i < j$$

where,

$$W = \sum_{i=1}^r \sum_{j=1}^r w_i(k) w_j(k)$$

### 3.2 Theory 2

The equilibrium point of Fuzzy control in Eq. (4) is the stability based asymptote. If we can prove that matrix  $P$  then the positive definite can find by equation.

$$\{A_i - B_i F_i\}^T P (A_i - B_i F_i) - P < 0, i = 1, 2, \dots, r \quad (7)$$

$$G_{ij}^T P G_{ij} - P < 0, i < j \leq r \quad (8)$$

The problem to design Fuzzy control system is to select the compensation  $F_i (i = 1, 2, \dots, r)$  therefore, in the condition of Eqs. (7) and (8), the problem of Fuzzy control is to find  $F_i$ . In this paper, we use Bode plot or Root locus to find the linear compensation.

Suppose that  $(A_i, B_i)$  is the control,  $A_i$  is state matrix, and  $B_i$  is input matrix when  $B_i = B = (i = 1, 2, \dots, r)$ . If the input matrix is equal and related to then

$$A_i - B F_i = G \quad (9)$$

where,  $G$  is Hurwitz matrix [1], If  $P$  is positive definite then.

## 4. DESIGN OF FUZZY CONTROL RULES

### Design of fuzzy control rules

From a design perspective, fuzzy control rule bases have been constructed based on the following:

- Domain expert's experience/control engineering knowledge. Up to now, most FLC designs have been based on the expertise and experience of domain experts, mostly arising from qualitative knowledge of and objective system, combined with control engineering knowledge. This is largely due to the fact that:
  - Fuzzy control rules provide a natural framework for capturing expert knowledge;
  - Many experts have found that fuzzy control rules provide a convenient way to express their domain knowledge.

Designing fuzzy control rule base by interrogating experts and trying to capture their approach in fuzzy rules is something of an art form. It is basically a heuristic approach, aimed at capturing the expert's rules of thumb. The method has nevertheless met with considerable success. It tends to be an iterative process, with the fuzzy parameters of the initial system being tuned and adjusted until satisfactory performance is achieved.

- Modeling the operator's control actions. In many control systems, the input-output relations are not known with sufficient precision to make it possible to employ classical control theory for modeling and simulation. Yet skilled human operators can control such systems quite successfully without having any quantitative models in mind. It is of ten possible to derive fuzzy control rules by modeling the operator's control actions. Designing fuzzy control rules in this way is basically a deterministic approach. In practice, modeling the operator's control actions is carried out by observing the human controller's actions over a period of time and expressing them in terms of the operational input-output data.

- Fuzzy modeling. Fuzzy modeling is a qualitative modeling scheme by which the behavior of the system to be controlled is qualitatively described using fuzzy quantities (or languages). This linguistic description of the dynamic characteristics of the controlled process may be viewed as a fuzzy model of the process. Based on the fuzzy model, we can generate a set of fuzzy control rules to obtain optimal performance of the system.
- Self-organizing/learning. Fuzzy control systems can be built which simulate human learning, and have the ability to create fuzzy control rules and to modify them based on system performance. Several schemes have been used to construct these systems, including the use of neural networks, self-tuning and self-organization.

## 5. EXPERIMENT AND ANALYSIS

The experiment of SCADA software uses boiler model at temperature 40-80 °C to control PID value in Fuzzy and Non-Fuzzy PLC. The Fuzzy PLC is shown in Fig. 6.

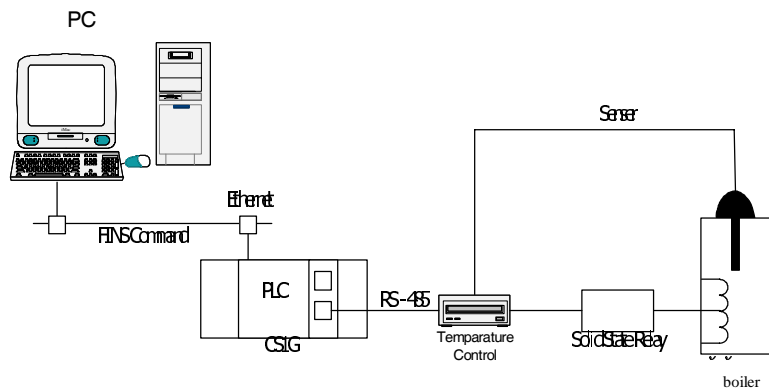
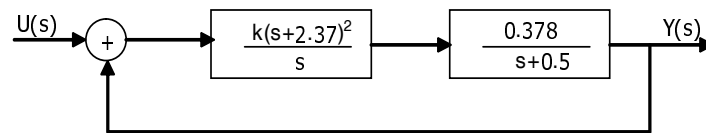


Fig. 6 Boiler system model simulation

In the test, we use PID control command in PLC and specify Input word, First parameter and output word in order to control the boiler model. In Fig. 6, the computer controls from SCADA via communication system typed Ethernet to PLC. This PLC has the PID command which can specify proportional band (%P), integral constant ( $T_{ik}$ ), derivative constant ( $T_{dk}$ ) and can use PID only one loop, therefore, the change of Set value will change by software value calculated from Fuzzy theory in order to get more efficient control value from boiler model which has volume 3.5 liters, voltage 220 V.AC 670W. We can design PID control and write the characteristic equation below.



The characteristic equation is

$$\frac{U(s)}{Y(s)} = \frac{10s^2 + 52.6s + 68.944}{11s^2 + 53.1s + 68.944}$$



Then, we design Fuzzy control system of boiler model by specifying  $X_1$  as temperature of boiler model and  $X_2$  as 0.

After that we compare  $X_1$  feedback temperature, with the calculating result and send to control parameters  $P$ ,  $T_{ik}$ , and  $T_{dk}$  in PLC.

The computation of Fuzzy

- Fuzzification is the change of control system to Fuzzy system
- Inference Engine is the analysis of conditions by using IF... THEN...
- Defuzzification is the comparison of all fuzzy outputs with result by Centriod method following Eq. (1)

And then take the value of Fuzzy controller to control the angle of Solid state relay controlling the heat of oil of boiler model. In the second process, we can give the condition of rule as seeing below:

$$L^1 : IF x_1 \text{ is OK THEN } \dot{X} = A_1 x + B_1 u$$

$$L^2 : IF x_1 \text{ is OK THEN } \dot{X} = A_2 x + B_2 u$$

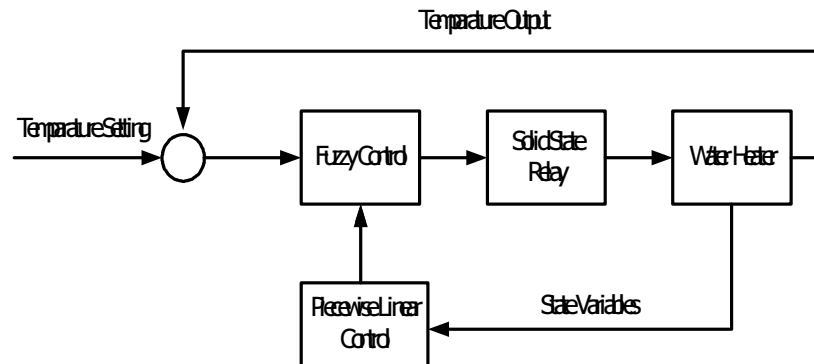


Fig. 7 Fuzzy control of Boiler model

In the Fig. 7, the output matrix in each rule of Fuzzy control is the result of the experiment by giving the temperature 20-80 °C to control the coil and the variable of boiler model and so take the value of variables from the experiment place to the boiler model and write output matrix of each rule following below:

$$A_1 = \begin{bmatrix} 0 & 1 \\ 0.48 & 0 \end{bmatrix} \quad B_1 = \begin{bmatrix} 0 \\ -0.618 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} 0 & 1 \\ 2.15 & 0 \end{bmatrix} \quad B_2 = \begin{bmatrix} 0 \\ -0.082 \end{bmatrix}$$

Specify feedback Eigen value  $[2.5364 \pm j0.6667]$  and then  $F_i$  is

$$F_1 = [-11.9058 - 8.2084] , F_2 = [-110.0953 - 61.8634]$$

$$G = A_1 - B_1, F_1 = A_2 - B_2, F_2 = \begin{bmatrix} 0 & 1 \\ -6.8778 & -5.0728 \end{bmatrix}$$

$$G_{12} = \frac{(A_1 - B_1 F_2) + (A_2 - B_2 F_1)}{2}$$

When put every value in equation above,  $G_{12}$  is

$$G_{12} = \begin{bmatrix} 0 & 1 \\ -33.1926 & -19.4523 \end{bmatrix}$$

And P can get from the suitable value of control system.

$$P = \begin{bmatrix} 1.1379 & 0.0798 \\ 0.0798 & 0.1201 \end{bmatrix}$$

From the condition above, the matrix P is positive definite so, the stability is considered following Learchunof continuous time

$$(A_i - B_i F_i)^T P + P(A_i - B_i F_i) < 0$$

$$G_{12}^T P + P G_{12} < 0$$

$$\begin{bmatrix} -5.2959 & -4.4005 \\ -4.4005 & -4.5130 \end{bmatrix} < \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$$

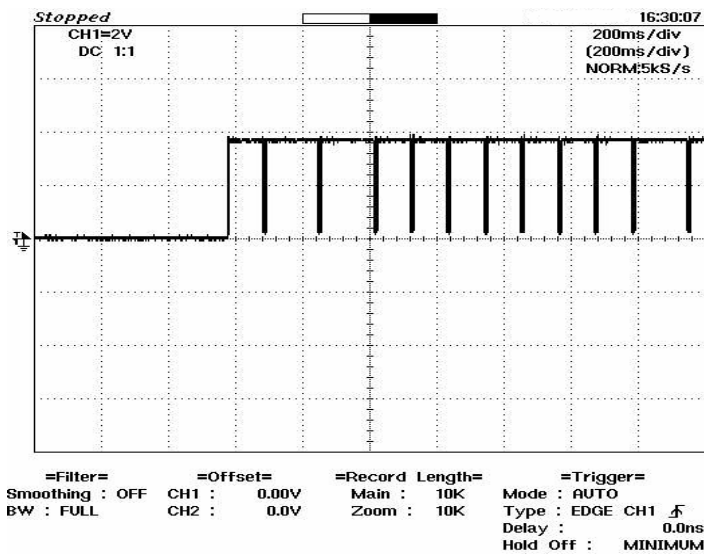


Fig. 8 Signal between PLC and Equipment controlling temperature typed RS-485,signal positive compare ground

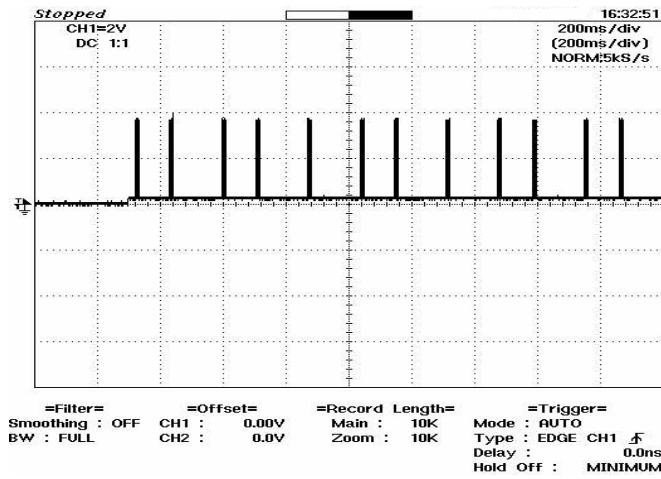


Fig. 9 The signal between PLC and Equipment controlling temperature typed RS-485, signal negative compare ground

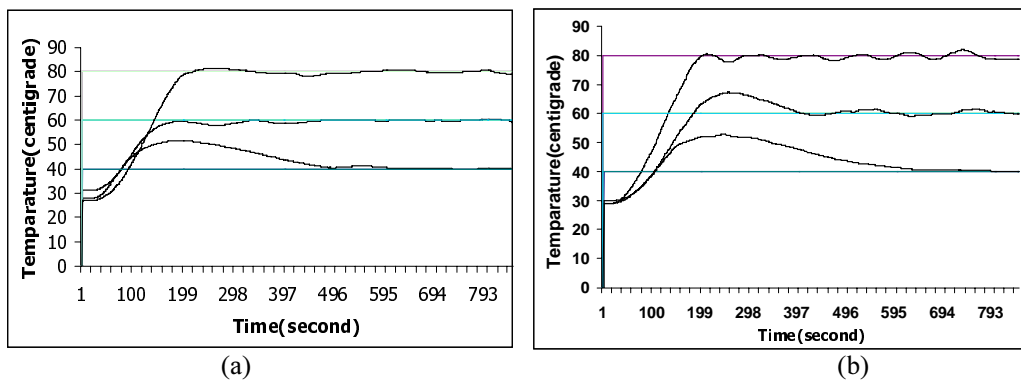


Fig. 10 Showing the temperature per time of parameter PID typed Fuzzy and Non-Fuzzy: (a) Fuzzy control (b) Non-Fuzzy control

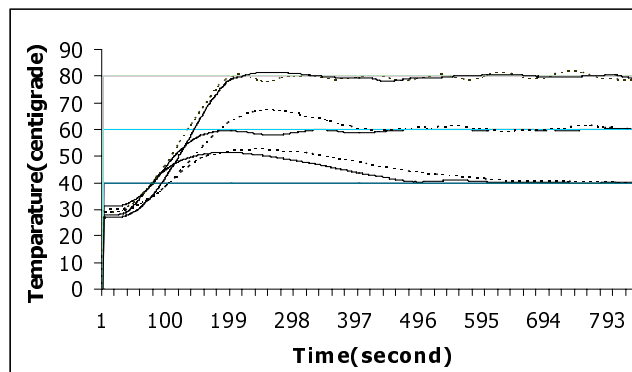


Fig. 11 The comparison of the temperature of PID parameter typed Fuzzy (Strength line) and Non-Fuzzy (Dot line)

## 6. CONCLUSIONS

At the present, the factory automation uses automatic control system via PLC and expands the capability after technology. It is important to study Control system and SCADA in order to develop the efficiency of the moderate and small factory in Thailand. In this paper, we use Visual Basic collaborating with PLC of Omron CS1G adding feedback control PID to increase the efficiency by Fuzzy control theory applying to Non-Fuzzy PLC module. Observing from the experiment of boiler system model, we found that PID value getting from Fuzzy PLC is more stable than Non-Fuzzy PLC. Therefore, we can summarize that controlling via SCADA system can develop the capability to the automatic process up to the experience and technology developed from general applying program.

## 7. REFERENCES

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