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Advanced pH Control Using Fuzzy Logic

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Abstract— *Advanced pH control is performed by using fuzzy logic. This paper discuss on achieving the set of objectives for the specific study. These includes using one model system developed for application of process control and to develop steady state model to generate data for synthesizing the basic process control strategy. The next study will be to develop feedback, feedforward, cascade, smith predictor and IMC control strategy in simulation environment. This paper proposes to study the basic control principles, tuning methods, and the pH control. The main software that is used in achieving the aim of the research is to use Simulink in MATLAB environment.*

Keywords— *Dynamic state; fuzzy Logic; pH control.*

I. Introduction

Nowadays, the advanced control techniques of industrial application become more demanding for process industries. This is due to the increasing complexity of the process and to produce better requirements in terms of product quality and environmental issues. Thus, a stable, efficient and flexible control system is required in continuing the operation of the process. There is also a need, for a variety of purposes including control system design, for improved process model to represent the types of plant commonly used in industry.

Advanced technology has major impact on industrial control engineering. There is a new method of advanced control technology that is increasing towards the use of a control approach known as "intelligent" control strategy. Intelligent control act as a control approach or solution that tries to imitate important characteristics of the human way of thinking, basically more on decision making processes and uncertainty. It is also a term that is commonly used to describe most forms of control systems that are based on artificial neural networks or fuzzy logic.

Usually a control theory can be successfully applied only when the system under control can be sufficiently analyzed and a useful mathematical model are used. When the process characteristics are known in advance, and are either constant or change predictably, a non-adaptive controller can be used to control it.

Difficulties arise in the control of the pH process due to the severe process non-linearity and frequent load changes [1]. For example, changes in the influent composition or flow rate. The non-linearity can be understood from the s-shaped titration curve. Frequent and rapid load changes are common for most waste water treatment facilities since the influents come from the waste of a number of sources. Therefore, it is difficult to analyze and derive the system model of a pH control process.

The theory of fuzzy sets and algorithms developed by Zadeh [2] can be used to evaluated these imprecise linguistic statements directly. Fuzzy logic provides an effective means of capturing the approximate nature of the physical world. Therefore, it can be used to provide an algorithm which can convert a linguistic control strategy based on expert knowledge, into an automatic control strategy [3].

The objectives are to be referred as a guideline to achieve the specific goal in current research. The general objectives are to understand the skills and knowledge about the research. Besides, to apply the knowledge gain and also to adapt with individual independent throughout the research. As for the research, the specific objectives are to test different control strategies on the pH and to provide the best result and to develop fuzzy logic compared with the best control strategies in order to gain optimum result.

The research will consists of two main parts; the first is to develop five different control strategies with the pH changes and get the best result. The control strategies involved are feedforward control, feedback control, cascade control, smith predictor control and integral model control (IMC). Second, choose the best control strategies and compared with the fuzzy logic on pH control. The scope of research will be analyzing the types of advanced control strategies available. This will include advantages and disadvantages for the specific control strategies on pH control.

II. Methodology

Generally, the development of the fuzzy logic and control schemes involves three steps as shown in figure 1. The first step is the fuzzification process. This process involves a domain transformation in which the system inputs or crisp inputs are converted into fuzzy set inputs. In the pH neutralization process the system inputs are actually the measured process variables such as the pH value in the tank, the flowrates of the streams and the conductivity values of the solutions. In this process each input will be transformed into its own group of membership functions or fuzzy sets. Thus the development of the controller must include the important system inputs, determining the type of membership function, as well as establishing the degree of the membership function for the input set.

The second step is the Fuzzy Inference process which is described as a process that forms the mapping of the fuzzy input and output sets. The main process involves establishing the relevant Fuzzy Set and Fuzzy Operator, as well as developing a set of "if-then rule statements". The last process prior to the next step is the aggregation process in which all the results of implication of each rule are combined into a single fuzzy set [4].

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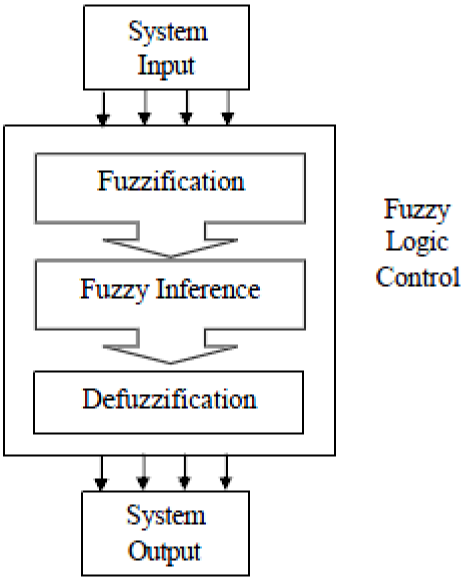

Fig. 1. General procedures of designing a fuzzy system.

The third step is an inverse process of the first step and called “defuzzification”. The process involves transforming the fuzzy set output into the system output so that the output signal can be used to drive some actuators by the controller. The final output from the defuzzification process is a single value [5].

A. *Fuzzy Inference System for the pH Controller*

Figure 2 below shows the MATLAB Simulink representation of the overall system for control. Generally the idea of the control approach adopted is that when the current pH value is below the desired value the Fuzzy Logic pH Controller will provide a new set point for the Fuzzy Logic Flow Controller.

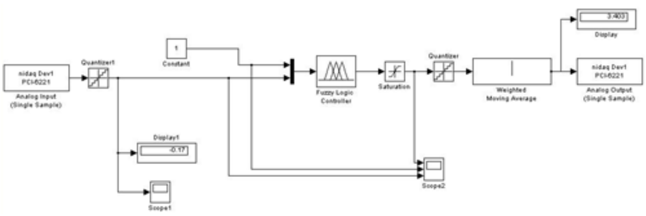

Fig. 2. SIMULINK block diagram of the pH controller.

B. *The Development of Fuzzy Logic Controller*

In this research, Fuzzy Logic Control (FLC) was developed by using Mamdani Fuzzy inference method. The FLC was designed individually as such to perform for servomechanism under set-point changes.

In the development of FLC, the input and output variables must first be defined by using the FIS Editor. For this research, the input is the flow controller and the output is the value of pH.

The process transfer function is used to relate between the amount mixing of acid and alkaline to produce salt and water to maintain the pH of the fluid inside the neutralization process. For the input and the output of FLC, each of them has their own membership function. The value of this function determines the element that belongs to the fuzzy set.

There are many types of membership function; triangular and trapezoidal are considered in the development of FLC. For the input membership function, triangular was used while for the output membership function the trapezoidal was used. Each of the input and output consists of numbers of membership function. Membership function was designed by using the Membership Function Editor for which each membership can be assigned with different types and values. Moreover, the range of the input and the output is very important in order to define the type and value of the membership function.

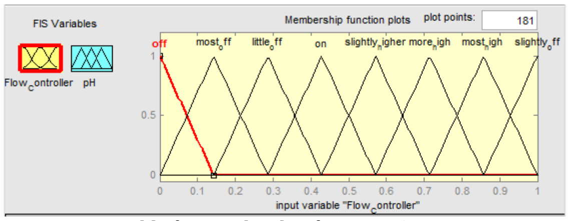

Fig. 3. Input variable for membership functions (Step input: Set-point changes).

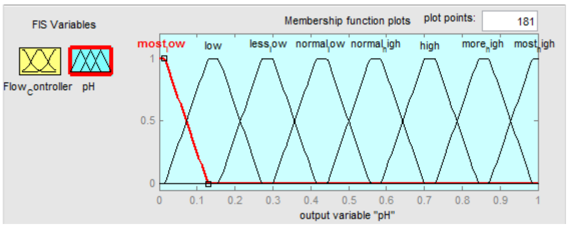

Fig. 4. Output variable for membership functions (Step input: Set-point changes).

Each of the membership functions for the input and the output variable are connected by using Rule Editor. The FLC will give the control response based on the input and the output which are connected by using these rules. Furthermore, the Fuzzy Inference System enables the view of the Rule Viewer and Surface Viewer in which will provide assistance for the further improvement of the FLC design.

List of Rules for Step input: Set-point Changes:
If (Flow Controller is off) then (pH is most_low)
If (Flow Controller is most_off) then (pH is low)
If (Flow Controller is little_off) then (pH is low)
If (Flow Controller is most_off) then (pH is less_low)
If (Flow Controller is most_off) then (pH is normal_low)
If (Flow Controller is most_off) then (pH is normal_high)
If (Flow Controller is little_off) then (pH is normal_high)
If (Flow Controller is on) then (pH is high)
If (Flow Controller is slightly_higher) then (pH is more_high)
If (Flow Controller is more_high) then (pH is most_high)
If (Flow Controller is slightly_off) then (pH is high)
If (Flow Controller is off) then (pH is normal_high)

III. Result and Discussion

The stability response result obtained for every control strategies will be presented in graphical form. Only those graphs which producing stable response will be presented.

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A. Result for the Best Control Scheme and the Best Controller Tuning

In this section, only the graphs producing overall stability according to the type of control scheme will be presented. The complete results of system stability based on each control schemes studied are summarize below.

Some of the general criteria of selection for the system stability are as the following:

-Producing stable responses

-Not much oscillation

-The value of error is small

Generally, the selection criteria will be much according to the following Figure 5.

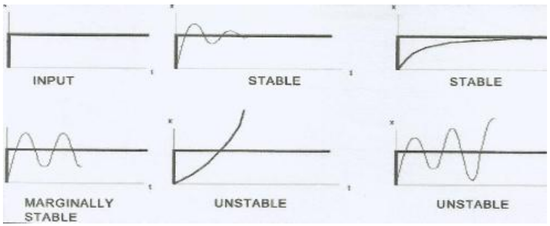

Fig. 5. Typical types of stability responses resulting from an input.

Based on the following result obtained, only feedback and cascade control that give the best tuning for pH control. The remaining control such as feedforward, smith predictor and IMC controller give unfavorable result for pH control. Thus, from different type of tuning method apply to these controller, it is observed that feedback and cascade controller give a better performance and small error with less overshoot. Below shows the result obtained from different type of tuning method.

For the best feedback controller strategies are shown in the figure below.

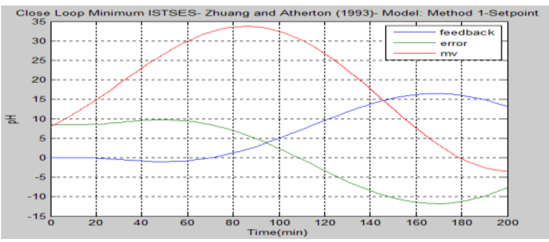

Fig. 6. Close loop minimum ISTSES- Zhuang and Atherton (1993).

The error has been calculated by using MATLAB Simulink Environment and the value are shown in the table below.

For the feedback controller:

TABLE I. Error value for feedback controller.

Tuning Method	Error Value
Close Loop IMC Response	617.02
Close Loop ISE Response	214.59
Close Loop Minimum ISE - Murrill(1967)	110.67
Close Loop Minimum ISE-Zhuang and Atherton(1993)	101.64
Close Loop Minimum ISTSE- Zhuang and Atherton (1963)	178.64
Close Loop Minimum ISTSES- Zhuang and Atherton (1993)	51.59

From the above table, it can conclude that the Close Loop Minimum ISTSES- Zhuang and Atherton (1993) has the less error with the value of 51.59 and it is the best controller tuning method for feedback controller [6].

While for cascade control, For the best cascade controller strategies are shown in the figure below.

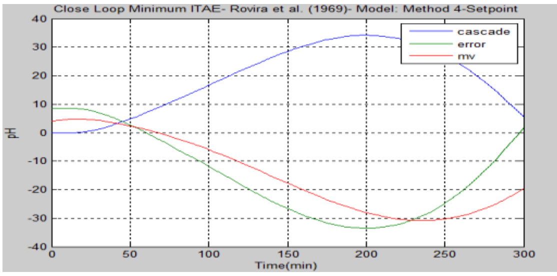

Fig. 7. Close loop minimum ITAE-Rovira et.al. (1963) Model method 4.

The error has been calculated by using MATLAB Simulink Environment and the value are shown in the table below.

For the cascade controller:

TABLE II. Error value for cascade controller.

Tuning Method	Error Value
Close Loop IAE Response	5020.1
Close Loop Chien wt al. (1952)- Servo Model Method 2	4604.3
Close Loop Minimum IAE- Marlin (1995)- Model Method 1	4183.4
Close Loop Minimum ITAE- Rovira et al. (1969)- Model Method 4	2826.7
Close Loop Minimum ITAE- Wang et al. (1995)- Model Method 1	4603.2

From the above table, it can conclude that the Close loop Minimum ITAW-Roviea er al. (1969)- Model Method 4 has the less error with the value of 2826.7 and it is the best controller tuning method for cascade controller.

B. Results for the Development of Fuzzy Logic Controller

The Feedback Control Scheme block diagram with the Fuzzy Logic Control used to analyze the response and performance of FLC are presented as in the following below figures. For the best result for feedback control block diagram compared with Fuzzy Logic Control are shown below.

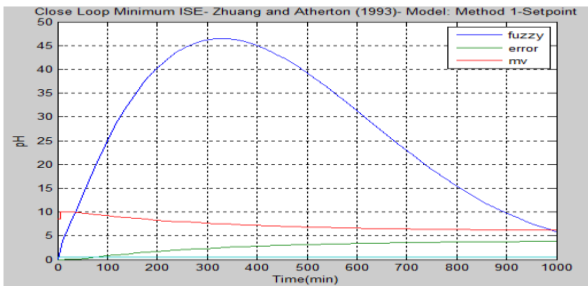

Fig. 8. Close loop minimum ISE-Zhuang and Atherton (1993)- Model method 1.

The error has been calculated by using MATLAB Simulink Environment and the value are shown in the table below.

For the feedback control with fuzzy logic control:

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TABLE III. Error value for feedback with fuzzy logic controller.

Tuning Method	Error Value
Close Loop IAE Response	123.56
Close Loop IMC Response	145.12
Close Loop Chien wt al. (1952)- Servo Model Method 2	186.24
Close Loop Hay (1998)- Servo Tuning Model	102.39
Close Loop Minimum IAE- Marlin (1995)- Model Method 1	112.02
Close loop Minimum ISE- Wang et al. (1995) Model Method 1	165.23
Close Loop Minimum ISE-Zhuang and Atherton (1993)- Model Method 1	102.25
Close Loop Minimum ITAE- Rovira et al. (1969)- Model Method 4	95.12
Close Loop Minimum ITAE- Cheng and Hung (1985) Model Method 8	76.12
Close Loop Minimum ITAE- Wang et al. (1995) Model Method 1	142.23
Close Loop Minimum ISTSE-Zhuang and Atherton (1993) Model Method 1	31.02
Close Loop Minimum ISTSES-Zhuang and Atherton (1993) Model Method 1	98.32

From the above table, it can conclude that the Close Loop Minimum ISTSE-Zhuang and Atherton (1993) Model Method 1 has the less error with the value of 31.02 and it is the best controller tuning method for feedback controller with fuzzy logic controller.

For the best result for cascade control block diagram compared with Fuzzy Logic Control are shown below.

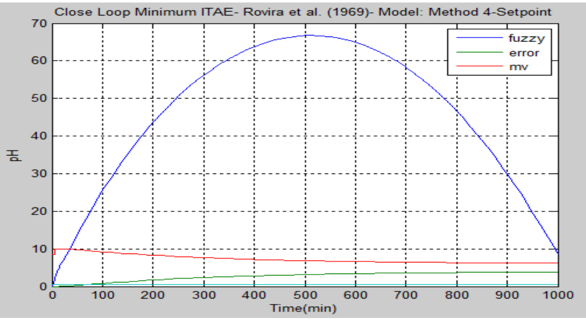

Fig. 9. Close loop minimum ITAE- Rovira et al. (1969)- Model method 4.

The error has been calculated by using MATLAB Simulink Environment and the value are shown in the below table.
For the cascade control with fuzzy logic control:

TABLE IV. Error value for cascade with fuzzy logic controller.

Tuning Method	Error Value
Close Loop IAE Response	3012.3
Close Loop Chien wt al. (1952)- Servo, Model Method 2	3412.9
Close Loop Hay (1998)- Servo Tuning Model	3012.5
Close Loop Minimum ITAE- Rovira et al. (1969)- Model Method 4	2503.6
Close loop Minimum ITAE- Wang et al. (1995) Model Method 1	3106.9

TABLE V. The comparison of response between feedback scheme with Fuzzy Logic Control scheme.

Characteristic	Control Scheme	
	Feedback Control	Fuzzy Logic Control
Oscillation	Significant Oscillation	No oscillation
Error Value	51.59	31.02

TABLE VI. The comparison of response between cascade control scheme with Fuzzy Logic Control scheme.

Characteristic	Control Scheme	
	Cascade Control	Fuzzy Logic Control
Oscillation	Significant Oscillation	No oscillation
Error Value	2826.7	2503.6

From the analysis, FLC provides better result than feedback and cascade control. FLC is one of the advanced process control approach but differ in terms of its mechanism to control the process. The conventional PI and PID controller use tuning formulas provided by many tuning handbooks, while Fuzzy Logic Control uses Fuzzy Logic Controller (FLC) with its own Fuzzy Set to control the process.

The FLC functions were developed based on the Fuzzy Inference System (FIS) in which consist of Membership Function Editor, Rules Editor, Rule Viewer and also Surface Viewer.

The Fuzzy Logic Controller (FLC) developed was optimized to perform with the step input changes. But unfortunately, it is discovered that the FLC designed for the step input can be considered unworkable for several tuning methods. This is because the software produces error while running the simulation for that particular design. Thus, for simplicity, the results for step input change were taken into consideration.

In the process of designing the Fuzzy Logic Controller (FLC), the most important aspect that needs to be considered is the proper formulation of the fuzzy rules to give the best performance of FLC. The advantages of FLC is that it has a better control on the controller as it could adjust and set the controller according to the current desired value. It will respond according to the range value of the input and the output of the membership functions and the rules that connect the input and the output of the membership functions.

IV. Conclusion

Fuzzy Logic Control is the latest advanced control scheme. From this research, it is concluded that cascade control scheme is robust and useful in the process control. However, there are certain areas in process control in which the existing advanced process control scheme give less effective control response. The Fuzzy Logic Control is one of the alternatives that can be employed to overcome this as it has the ability to cover wider range processes because it uses human-like techniques to define the process. Based on this research, the Fuzzy Logic Control should be considered as a new solution approach in the process control field and it also can be applied in the larger scale in the industry.

Based on the problem encounter during the development of Fuzzy Logic Controller (FLC), it's suggested that new FLC should be designed specifically to handle several tuning methods. This would ensure that the FLC can be used specifically and can performed to solve for different tuning methods.

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