A Robust Temperature Control in BMS Using Fuzzy Logic

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ABSTRACT — **The paper is devoted to design and implement of a robust temperature controller in a Building Management System (BMS) using Fuzzy logic. The proposed controller is based on controlling the output of the 3 way valve to mix two fixed temperature water paths to achieve the selected temperature inside the desired range. The control objective is defined in terms of a Fuzzy goal and a Fuzzy decision-maker is used to find the membership function of the optimum Fuzzy control signal at each sample time. Advantages of this method include model transparency, the possibility to insert expert knowledge into the model generation, and economy in computational effort in generating model output. A software program implementing the proposed approach has been developed in the framework of Matlab program. Experimental data were extracted from the system. The performance of the Fuzzy model-based controller is compared to that of a conventional PID controller. Results show that satisfactory control of the temperature is possible, with a minimum of control activity. Finally, some conclusions are introduced.**

Index Terms — **BMS, Fuzzy Logic**

I. INTRODUCTION

Fuzzy logic is a powerful problem-solving methodology with a myriad of applications in embedded control and information processing. It was introduced by Dr. Lotfi Zadeh of UC/Berkeley in the 1960's as a means to model the uncertainty of natural language. Thus recently researchers have also introduced Fuzzy logic into the BMS controllers [1-5]. Fuzzy provides a remarkably simple way to draw definite conclusions from vague, ambiguous or imprecise information. Several research study BMS toward automation between them [6-7]. Also some researches simulate the performance of the BMS using Matlab [8-14]. This work intended to design and implement of temperature control of BMS using Fuzzy logic. Fuzzy logic resembles human decision making with its ability to work from approximate data and find precise solutions. Unlike classical logic which requires a deep understanding of a system, exact equations, and precise numeric values.

Fuzzy Logic has been gaining increasing acceptance during the past few years. There are over two thousand commercially available products using Fuzzy Logic, ranging from washing machines to high speed trains. Nearly every application canpotentially realize some of the benefits of Fuzzy logic, such as performance, simplicity, lower cost, and productivity. Fuzzy logic has been found to be very suitable for embedded control applications. Several manufacturers in the automotive industry are using Fuzzy technology to improve quality and reduce development time. The proposed temperature control system is assembled experimentally and tested which gives results incooperates with the controller design. Fuzzy controller is simulated to predict the transfer characteristics and gives satisfactory results. In this paper, the validity of fuzzy logic control as an alternative approach in temperature control applications is investigated. The paper consists of five sections. The first section is an introduction to the paper. The second section introduces the control system theory while the third section demonstrates the proposed system. The fourth section is the experimental and simulation results. Finally the conclusion section terminates the work.

II. CONTROL SYSTEM THEORY

Conventional Control Systems

A typical block diagram of a feedback control system is shown in Fig. 1[15].

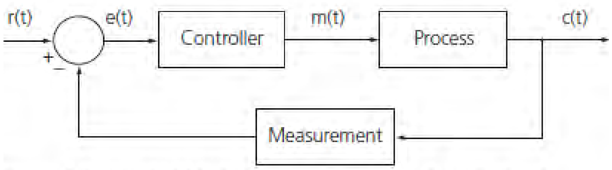

Fig. 1. A Typical block diagram of a feedback control system

The system consists of three main blocks: the process to be controlled, measurement, and the controller. The output of the process is measured and converted to an equivalent electrical signal using suitable sensor circuitry. The signal that represents the output, $c(t)$, is then compared with an input reference signal, $r(t)$, resulting in an error signal, $e(t)$. This error signal actuates the controller to generate the control action signal, $m(t)$.

Fuzzy Logic Controller (FLC)

The block diagram shown in Fig. 1 is still applicable in Fuzzy applications. Fig. 2 shows the basic structure of a Fuzzy logic controller. The main building units of an FLC are a fuzzification unit, a Fuzzy logic reasoning unit, a knowledge base, and a defuzzification unit. Defuzzification is the process of converting inferred Fuzzy control actions into a crisp control action. The fuzzy knowledge-base has a rule-base that maps a Fuzzy input variable, *E*, into a Fuzzy output, *U*.

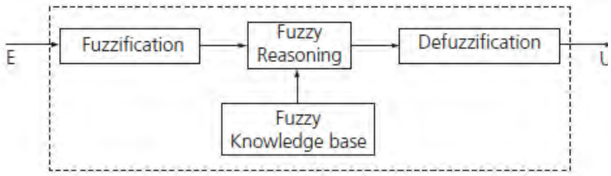

Fig. 2. Basic Structure of a Fuzzy Logic Controller (FLC)

This can be expressed by a linguistic statement such as:

$E \rightarrow U$ (condition *E* implies condition *U*)

which may be written as:

IF *E* THEN *U*.

The Fuzzy knowledge-base also has a database defining the variables. A Fuzzy variable is defined by a Fuzzy set, which in turn is defined by a membership function. Fuzzy reasoning is used to infer the output contributed from each rule. The Fuzzy outputs reached from each rule are aggregated and defuzzified to generate a crisp output.

Design

In the design of an FLC system it is assumed that:

- A solution exists.
- The input and output variables can be observed and measured.
- An adequate solution (not necessarily an optimum one) is acceptable.
- A linguistic model can be created based on the knowledge of a human expert. In order to model a system linguistically, one needs to:
- Identify the input and output variables of the process to be controlled (the plant). For example: speed, temperature, humidity, etc.
- Define subsets that cover the universe of discourse of each variable and assign a linguistic label to each one. For example, the linguistic variable *speed* may be defined as three Fuzzy subsets: *slow, medium*, and *fast* as shown in Fig. 3.
- Form a rule-base by assigning relationships between inputs and outputs.
- Determine a defuzzification method to be used to generate a crisp output from the Fuzzy outputs generated from the rule-base.

Basic Concepts of Fuzzy Sets

A Fuzzy set is a set where degrees of membership between 1 and 0 are allowed; it allows partial membership. Fuzzy sets can thus better reflect the way intelligent people think. For example, an intelligent person will not classify people as either friends or enemies; there is a range between these two extremes. Not recognizing that there are degrees in every trait can lead to erroneous decisions. Vague human expressions such as *tall, hot, cold*, etc. can be expressed by Fuzzy sets of the form,

$$A = \{(x, \mu_A(x)) | x \, X\} \quad (1)$$

where *X* represents the universe of discourse and $\mu_A(x)$ assumes values in the range from 1 to 0.

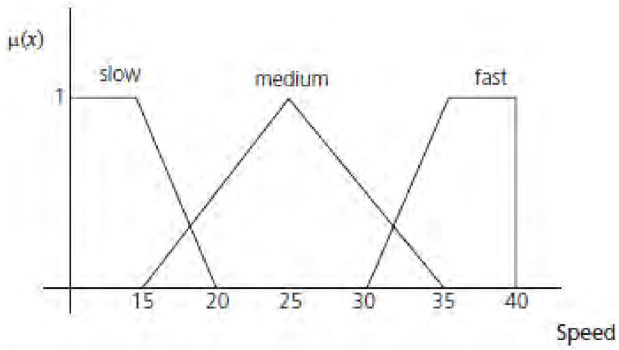

Fig. 3. Possible graphical representation of Fuzzy sets

Determination of Membership Functions

Discrete and continuous membership functions of a Fuzzy set are intended to capture a person's thinking. Fuzzy membership functions can still be determined subjectively in practical problems based on an expert's opinion. In such a situation one can think of membership functions as a technique to formalize empirical problem solving that is based on experience rather than the knowledge of theory. The expert's way of thinking can be captured either directly or through a special algorithm. Such determination could become more focused by physical measurements if the need arises. Available frequency histograms and other probability data can also help in constructing the membership function. It is important, however, to note that membership function values, or grades of membership, are not probabilities and they do not have to add to 1. Membership construction can be further simplified by selecting their form from the smaller family of the commonly used ones.

Fuzzification

Fuzzification is the process of making a crisp quantity Fuzzy. We do this by simply recognizing that many of the quantities that we consider to be crisp and deterministic are actually not deterministic at all; they carry considerable uncertainty. If the form of uncertainty happens to arise because of imprecision, ambiguity, or vagueness, then the variable is probably Fuzzy and can be represented by a membership function [16].

Defuzzification

For a given input, several IF/THEN rules could be launched at the same time. Each rule would have a different strength, because a given input may belong to more than one Fuzzy set, but with different membership values. In general, the output of the Fuzzy reasoning would involve more than two Fuzzy sets; therefore, one can write:

$$F = \bigcup_{i=1}^{k} F_i \quad (2)$$

Assuming the support of F is $X = \{x1, x2, x3, \ldots\}$ then for $x_i \in X$, $F(xi) = w_i$ indicates the degree to which each is suggested by the rule-base as a good output for the given input. The defuzzification operation is applied on F to determine the best crisp output. Numerous defuzzification methods have been suggested in the literature; however, sometimes different authors name the same method differently. No method has proved to be always more advantageous than the others. The selection of which method to use depends primarily on the experience of the designer [17].

Centroid method

This method is also known as the *center of mass*, or *center of gravity* method. It is probably the most commonly used defuzzification method. The defuzzified output, x^* is defined by,

$$x^* = \int \frac{\mu_F(x)\,\mathrm{xdx}}{\mu_F(x)\,\mathrm{dx}} \quad (3)$$

where the symbol ∫ denotes algebraic integration. Fig. 4. Represent this method graphically [18].

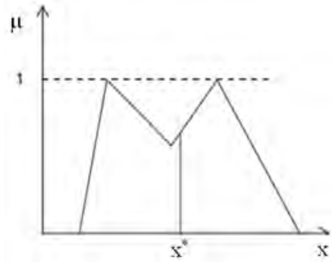

Fig. 4. Centroid Method

Center of largest area method

This method is applicable when the output consists of at least two convex Fuzzy subsets which do not overlap. The result is biased towards a side of one membership function.

First maxima method

This method is applicable when the output is peaked; the smallest value of the domain with maximum membership is selected.

Center of sums method

This method uses the algebraic sum of the individual Fuzzy subsets instead of their union. Although the calculations become faster, this method leads to adding the intersecting areas twice.

III. The Proposed System

The proposed system block diagram is shown in Fig. 5 which consists of 3 way valve and controller. The valve has two inputs and one output, the two inputs must have the same flow rate and the same pressure. The output flow rate is one of the two inputs flow rate, not the sum of them because the output is a percentage from the two inputs by opening port and closing the other port at the same time but with opposite percentage as indicated in fig. 6.

Energy balance equations then will be,

$$m_1 c_p T_1 + m_2 c_p T_2 = m_3 c_p T_3 \quad (4)$$

where m_1, m_2, and m_3 are the flow rate at the first, second input , and the output of the valve respectively. T_1, T_2, and T_3 are the temperature of at the first, second input, and the output of the valve respectively. The parameter c_p is assumed to be constant then,

$$m_1 T_1 + m_2 T_2 = m_3 T_3 \quad (5)$$

Then

$$m_1 + m_2 = m_3 \quad (6)$$

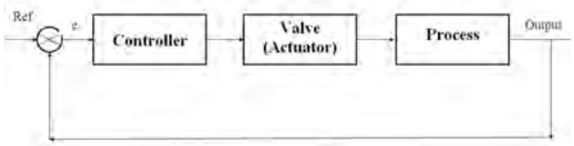

Fig 5. The Proposed system block diagram

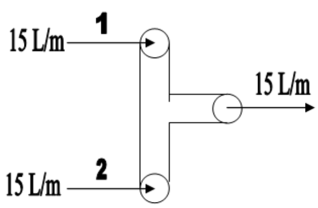

Fig 6. The principle of operation of the 3 way valve

The MS-22353 Proportional Valve Actuator is a non-spring return actuator used with proportional 2 to 10 Vdc or 4 to 20 mA controllers and standard 1/2" three-way valve bodies for control of heating and cooling coils [19].
The schematic diagram of the system assembled experimentally is shown in fig. 7.

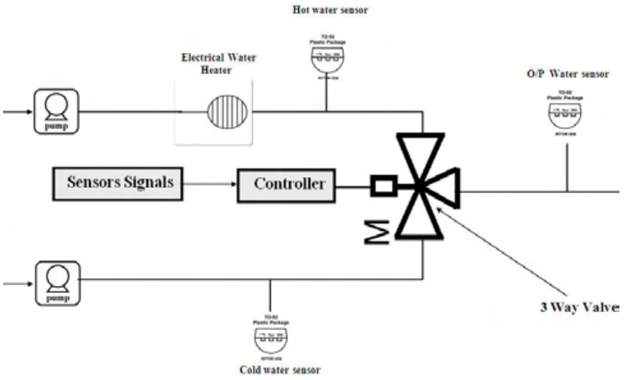

Fig 7. The schematic diagram of the assembled system

The used temperature range used from 32 ^oC to 48 ^oC which construct the membership function as indicated in Fig. 8. The corresponding output voltage range of the controller membership functions is indicated in Fig. 9. The temperature range is divided into nine membership functions are LL, LM, LH, ML, MM, MH, HL, HM, and HH. The valve voltage range is divided into nine membership functions are V1, V2, V3, V4, V5, V6, V7, V8, and V9. The Fuzzy rules are illustrated in table (1). A triangle membership function and centroid defuzzification method is used with the controller.

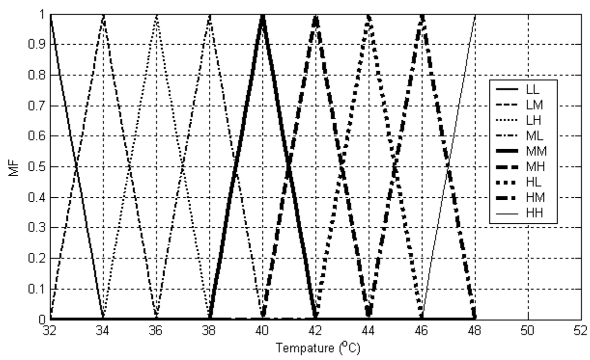

Fig 8. The Membership functions of the temperature range

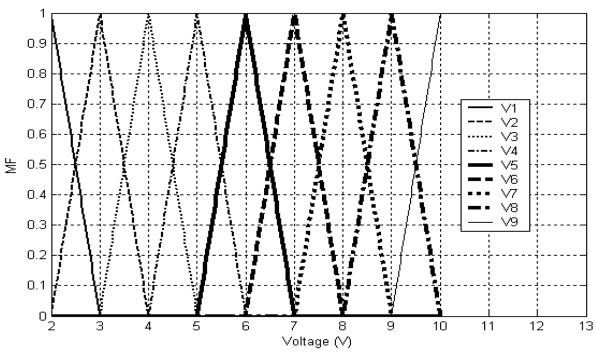

Fig 9. The Membership functions of the valve voltage range

Table (1): the Fuzzy rules

1	*If (Temperature is LL) Then (Valve Voltage is V1)*
2	*If (Temperature is LM) Then (Valve Voltage is V2)*
3	*If (Temperature is LH) Then (Valve Voltage is V3)*
4	*If (Temperature is ML) Then (Valve Voltage is V4)*
5	*If (Temperature is MM) Then (Valve Voltage is V5)*
6	*If (Temperature is MH) Then (Valve Voltage is V6)*
7	*If (Temperature is HL) Then (Valve Voltage is V7)*
8	*If (Temperature is HM) Then (Valve Voltage is V8)*
9	*If (Temperature is HH) Then (Valve Voltage is V9)*

V. EXPERIMENTAL AND SIMULATION RESULTS

The system is assembled experimentally as shown in Fig.7 and the controller is used manually to control the operation of the 3 way valve. The results are shown in Fig. 10 which represents the output control with manually steps of the controller. The simulation results of the Fuzzy controller are shown in Fig. 11 which demonstrates the defuzzification process. The system is simulated under two assumption of the membership functions; the first with 3 membership function to represent the temperature range and the voltage range. The second assumption is proposed one with nine membership functions. A comparison between the transfer characteristics of the controller under the two assumptions is shown in Fig. 12. This indicates that number of MF's improving significantly the transfer characteristics of the system. The generated error in the transfer characteristics is shown in Fig.13. The Fuzzy controller is simulated with temperature control system and the transient response is shown in Fig. 14 during the temperature variation. Sliding and rising transient characteristics are shown in Fig.15. Fig. 16 shows the transfer characteristics of the ideal, Fuzzy, and quantized controller and indicates that the controller has superiority for controlling such system than the quantized method.

The Fuzzy logic controller with the temperature control system is simulated using Matlab Simulink to compare the step response of the FLC with the previous PID controller. Fig. 17 shows the Simulink Model proposed for the temperature control system. The model is implemented using MATLAB software and comparison between Fuzzy logic controller and PID controller has been demonstrated, as shown in Fig. 18 with 3 membership functions. The step up transient of the controllers is shown in Fig. 19, while step down transient demonstrated in Fig. 20. Fig. 21 illustrates the same comparison with 9 membership functions. The transient response in this case is demonstrated in Fig. 22, 23. It can be concluded from the illustrated figures that FLC performance is acceptable. Fig. 24 shows the valve control during the simulation process.

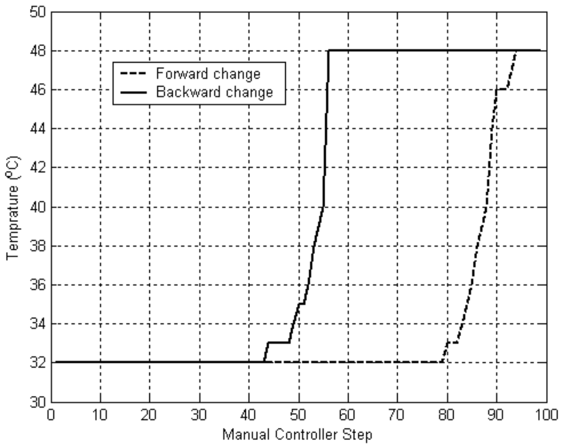

Fig 10. Experimental transfer characteristics of the system

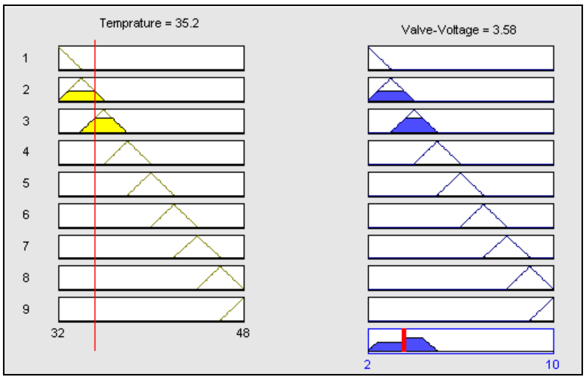

Fig 11. The simulation of the defuzzification process

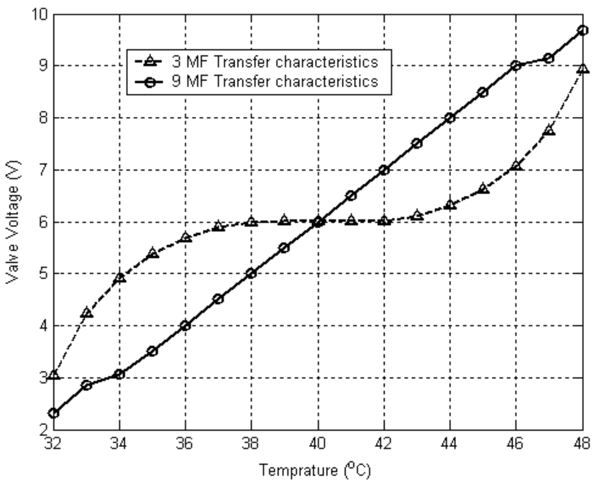

Fig 12. The Fuzzy controller T.C with 3&9 MF

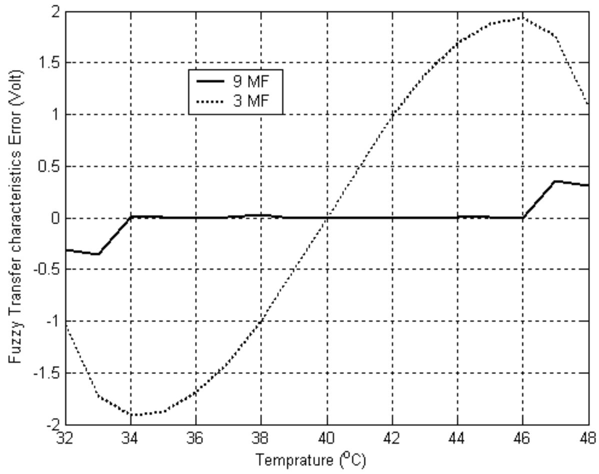

Fig 13. The Fuzzy controller T.C error with 3&9 MF

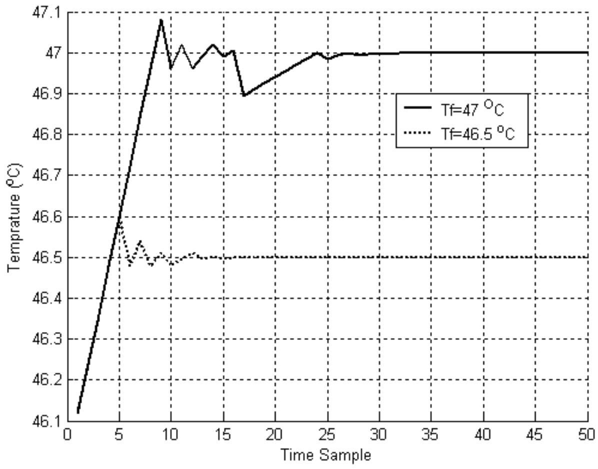

Fig 14. The transient response of the system

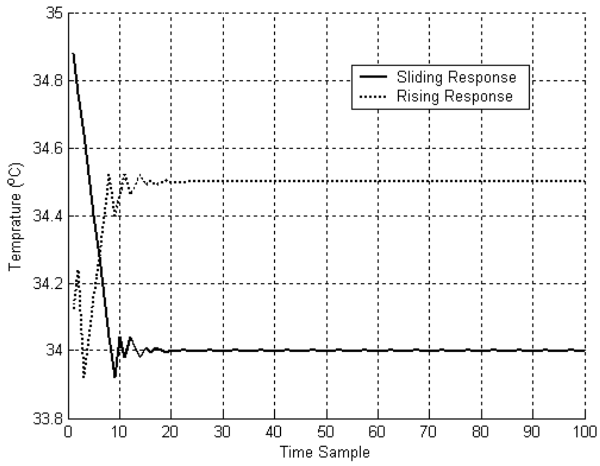

Fig 15. The transient response of the system

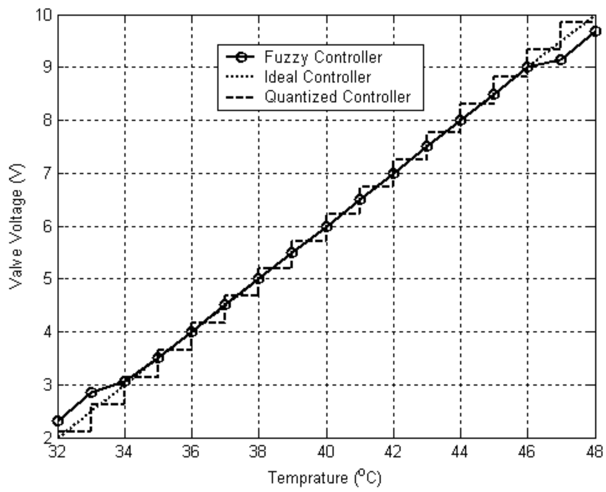

Fig 16. Comparison of controllers T.C' s for the system

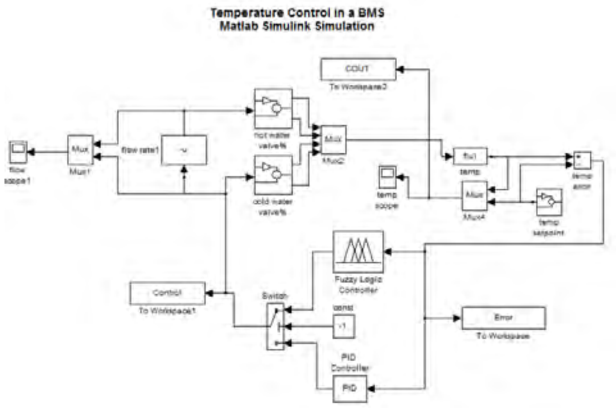

Fig 17. FLC Simulink Model schematic diagram

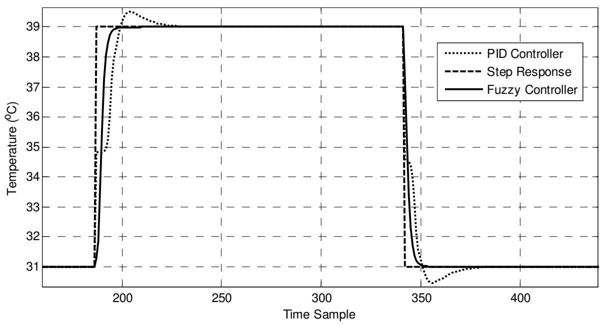

Fig 18. A transient response of 3 MF FLC compared with PID controller

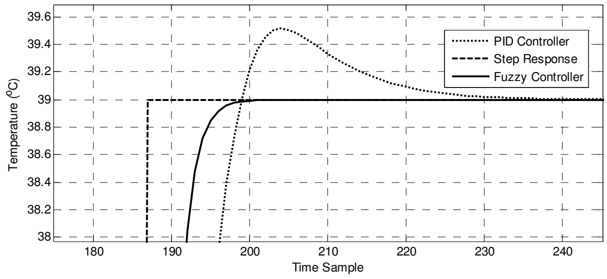

Fig 19. A step up transient response of 3MF FLC compared with PID controller

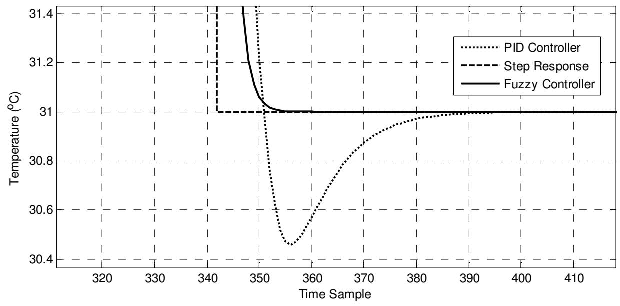

Fig 20. A step down transient response of 3 MF FLC compared with PID controller

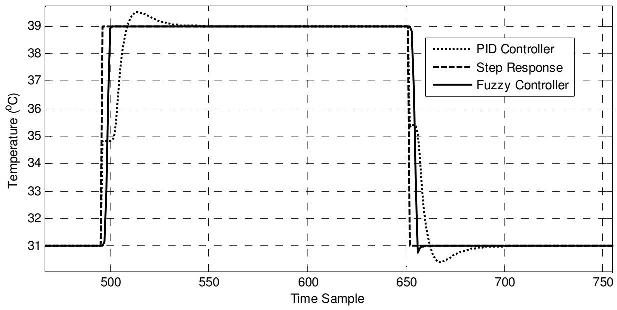

Fig 21. A transient response of 9 MF FLC compared with PID controller

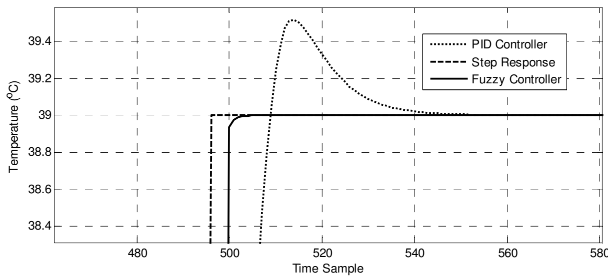

Fig 22. A step up transient response of 9MF FLC compared with PID controller

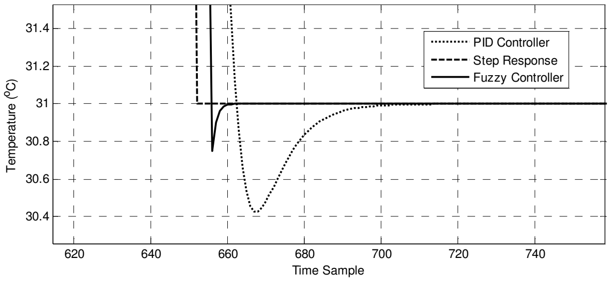

Fig 23. A step down transient response of 3 MF FLC compared with PID controller

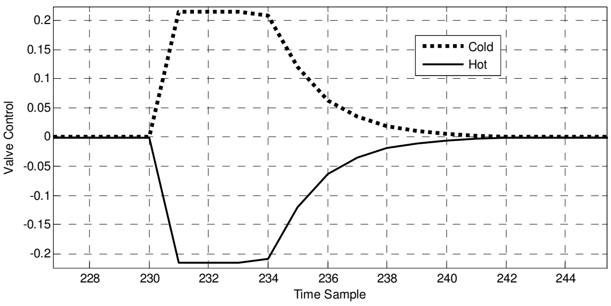

Fig 24. A 3 Way Valve control during the simulation process

IV. CONCLUSION

A temperature control BMS system using Fuzzy logic controller is proposed. The proposed controller is based on controlling the output of the 3 way valve to mix two fixed temperature water paths to achieve the selected temperature inside the desired range. The proposed temperature control system is assembled experimentally and tested which gives results in cooperates with the controller design. The proposed Fuzzy logic controller was applied to two different temperature processes and significant improvements in the system performance are observed in both cases. Furthermore, the stability of the FLC is investigated and a safeguard is established. The performance of the Fuzzy model-based controller is compared to that of a conventional PID controller. Results show that satisfactory control of the temperature is possible, with a minimum of control activity.

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