SUPERVISORY FUZZY LOGIC CONTROLLER USED FOR PROCESS LOOP CONTROL IN DCS SYSTEM

M. ABD EL-GELIEL
Arab Academy for Science and Technology
Department of Electric and control Eng.
P.O.1029 Miami, Alexandria, Egypt
mostafa@eng.aast.edu

Prof. M. A. El-Khazendar
Tanta University
Elec.Power &Machine Dept.
Tanta, Egypt
m_a_khazendar@hotmail.com

Abstract - In this paper, the designed schemes for two Mamdani fuzzy controllers, employing the scaling factor tuning are proposed. The first fuzzy logic controller, is a normalized controller used to control the process loops, the tuning for its input and output-scaling factors is done through the second fuzzy controller (the supervisory controller). The supervisory fuzzy controller tunes the normalized fuzzy controller based on the variation of the loop response.

The normalized fuzzy controller and the supervisory fuzzy controller are organized with specific experience information about a nonlinear thermal process. The proposed fuzzy controllers are applied practically to control the thermal process. That controller is applied to another process (level control process), where the controller gains are selected based on the process conditions and limitations.

The great advantage of that contribution is the ability to be generalized for different process variable loops in Multi-input/output system or any DCS system. The supervisor here make a decouple between the process

Keywords: Normalized fuzzy controller, supervisory fuzzy controller, scaling factor tuning, and DCS systems control loop.

1- INTRODUCTION

The dynamic characteristics of most control system are not constant because of several reasons, such as deterioration of components as time elapse or change in parameters and environment. A satisfactory system must have the ability to adaptation. Adaptation implies the ability to self-adjustment or modification in accordance with an unpredictable change in the condition of the environment or structure. In many cases, the physical measurements of the pertinent quantities are very difficult and expensive. These difficulties lead to explore the use of "Artificial Intelligence" (AI) [1-4] as a way of obtaining models based on the experimental measurements. One of the superior capabilities of fuzzy system, as an AI technique, is that it can use the information expressed in linguistic pattern [1-8]. Though most fuzzy system have been formed to emulate human decision making behavior, the linguistic information stated by an expert may not be precise, or it may be difficult for the expert to articulate the accumulated knowledge to encompass all circumstances. Hence, it is essential to provide a tuning capability [9] for fuzzy system to generate or modify the controller parameters on line in real system and it is an important issue in intelligent control. Thus, the human operator (supervisor) is often required to provide on line adjustment, which makes the process performance greatly dependant on the experience of the individual operator [10]. The development of controllers capable of generating tuning parameters of fuzzy controller to obtain the desired dynamics for the plant is of a great importance. There are many parameters can be adapted on line in fuzzy controller (universe of discourse, FIS, FAM, etc.) some of the adaptation methods (proposals) in [4,9,11,12]. Adjustable scale factor of normalized fuzzy controller [4] are one of the adaptation parameters. Some of the scale factor selection methods are explained in [4,13,14,15]. In this work, a fuzzy controller that self-adapts the parameters, mainly the input and the output gain coefficients is proposed, using only qualitative knowledge of the plant. The controller will start with a set of fixed parameter (normalized fuzzy controller with input scale factor and output scale factor) and through the supervisory fuzzy controller, the scale factors of the normalized fuzzy controller are adjusted or adapted. The adaptation of scale factors are done by two methods, the output-input scale factors are tuned due to the error between the reference input and actual output firstly. Finally input-output scale factors are tuned according to the error between the desired response ad the actual response (model reference adaptive technique)[17]. This adjustment is accomplished in continuous time. The analysis of the robustness of the proposed algorithms is performed for different real-time situation of the case study (Thermal process).

The same control algorithm is applied to control level process with the same tuning parameters (with-out retuning and prior information about the process) but the input-output signal level is changed according to sensor and actuator voltages limits.

The response in the two cases (level and thermal) is acceptable. So this approach can be generalized in DCS system to control different loops (variables).

2- NORMALIZED FUZZY CONTROLLER AND SUPERVISORY CONTROLLES

The first stage of the fuzzy controller operation is the fuzzification and the last one is the defuzzification. On both stages, the membership functions that describe the different values of the linguistic variables are applied. To choose membership function, first of all one needs to consider the universe of discourse for all the linguistic variables, applied to the rules formation. To specify the universe of discourse, one must firstly determines the applicable range foe the characteristics variable in the context of the system designed. It is usually desirable to scale, or normalize, the universe of discourses of an input/output variable, where a reasonable choice of one case can be unsuitable for another case of the system operation. Normalization means applying the

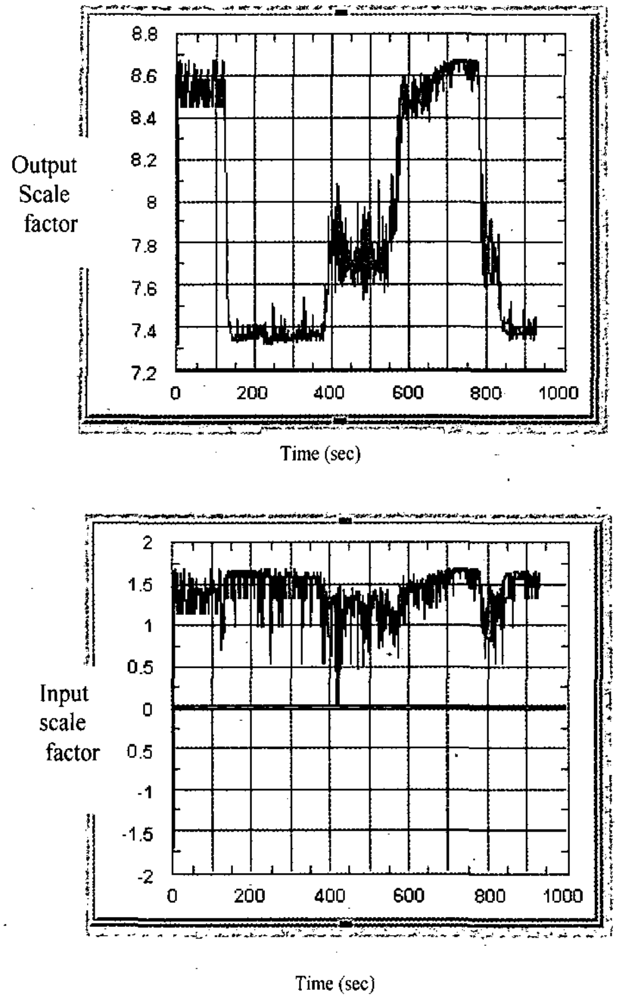


Fig. 14 output and input scale factor of response Fig.13

5- CONCULOSION

In this paper, a fuzzy controller with self adapted scale factors using another supervisory fuzzy controller is implemented, and its robustness is checked when disturbance occur. It is shown that, this type of controller can be generalized with different inputs/outputs ranges for different loops and different variables in DCS system, which needs a simple and fast controller.

Using a scale factor tuning limits the FLC parameters, this needs to tune, such as membership functions, rule base, fuzzy inference, etc. The priority of supervising output scale factor is selected duo to its direct impact on stability and oscillation tendency. But input scale factor has the most influence on basic sensitivity of the controller. Supervisory controller can tune both input and output scale factors according to the required performance. Using model reference with supervisory fuzzy controller forces the process to follow the desired specifications hence it is preferred in case of the specified performance required. If the required from the process is to achieve some accepted performance not specific performance both supervisory controllers introduced could achieve the performance required hence the simplest one is preferred.

6- REFERENCE

[1] L. H. Tsoukvlas and R. E. Uhring, "Fuzzy and Neural Approaches in Engineering", John Wiley Sons, inc., 1997

[2] H. Hargras, "Applications on Fuzzy Logic Control, Genetic Algorithms in Intelligent process Control", M. Sc. Thesis, Alex. University, 1996.

[3] C. J. Harris, C. G. Moore, and M. Brown, Intelligent Control Aspects of Fuzzy Logic and Neural Nets, World Scientific, 1993.

[4] Leonid Reznik, "Fuzzy Controllers", Newness, 1997.

[5] L. A. Zadeh, Fuzzy sets, Information Control, vol. 8, pp. 338-353, 1965

[6] T. W. Vaneck, "Fuzzy Guidance Controller for an Autonomous Boat", IEEE Transaction on control system, pp 43-51, April 1997.

[7] T. Terono, K. asai, and M. Sugeno, "Applied Fuzzy Systems", USA, 1997.

[8] J. M. Mendel, "Fuzzy Logic Systems for Engineering: A tutorial", Proc. IEEE, vol. 83, pp. 345-377, 1995.

[9] Marco Russo Lakhumi C. Join, Fuzzy Learning and Applications, CRC Press, 2001

[10] Han-Xiong Li and Shouping Guan," Hybrid Intelligent Control Strategy", IEEE Control System Magazine, pp 36-48, June 2001

[11] L. X. Wang, Adaptive Fuzzy System & Control design & Stability Analysis, Prentice-Hall, 1994.

[12] Junhang Nie and Derek. A. Linkens, Fuzzy-Neural Control Principle, algorithms and application, Prentice-Hall Europe, 1995.

[13] Plam R. "Scaling of Fuzzy Controllers Using the Cross-correction", IEEE Transaction on Fuzzy Systems, vol. 3 no1, pp 116-130, 1995.

[14] Yager R. R. and Filer D. P. Essentials of Fuzzy Modeling and Control, John Wiley, 1994.

[15] Renznik L. and Stoica A., "Some Tricks in Fuzzy Controller design", In: Proceedings of Australia and new Zealand Conference on Intelligent information systems, ANZIIS-93, IEEE, Perth, Western Australia, pp. 60-64, 1993

[16] M. A. El-Geliel, "Computer Based control of Thermal Process Using Fuzzy Logic and PID controller", M.Sc. Thesis, Arab Academy for Science and Technology, June 2000

[17] Kal Johan Astroum and Bjorn Wittenmark, "Adaptive control", Addison-weslly, 1995

standard range of [-1, +1] for the universe of discourses of the inputs and the outputs. The structure of the fuzzy controller is shown in Fig. 1.

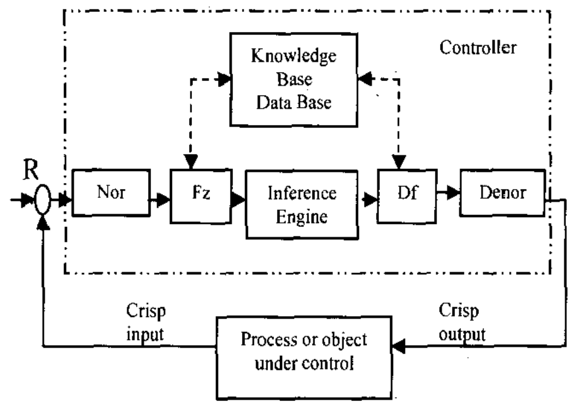


Fig. 1 Block diagram of normalized fuzzy controller

In the case of the normalized universe of discourse, an appropriate choice of specific operating areas requires scaling factors. An input scale factor transforms a crisp input into a normalized input in order to keep its value within the universe. An output-scaling factor provides a transformation of the defuzzified crisp output from the normalized universe of the controller output into an actual physical output [4]. Some priority list of scale factor choice is recommended in [13]. Similarity between coefficient Ki and Kp of the PI controller and the scaling factors of the normalized fuzzy controller is analyzed in [14]. Selection of scale factors by trail and error is suggested and recommended in [4]. In this study, firstly tuning scaling factor of input and output is achieved using trail and error based on the human experience. After that the tuning is achieved using another fuzzy controller (supervisor). In the two cases the procedure of tuning the factors is related to the research results in [15].

The main objectives of supervisory controller are tuning on lines the scale factors of the normalized fuzzy controllers. The tuning procedure depends on trail an error (human supervision) or adaptation algorithms.

The output gains of the supervised fuzzy controllers depend on the error signal between the reference input to the process and the actual output as shown in Fig.2. In this case the system response can perform accepted specification but if it is desired to force the over-all system to achieve a desired specification such as overshoot, rise time etc... the output gains should be related to that specifications. Model reference adaptive technique is one of the adaptation methods used o force the system performance to achieve a specified specification [3, 17]. Fig. 3 shows the over-all block diagram of the model reference supervisory controller where, the input signals to the supervisory controller are error (between the desired model and actual output of the process) and its rate of error.

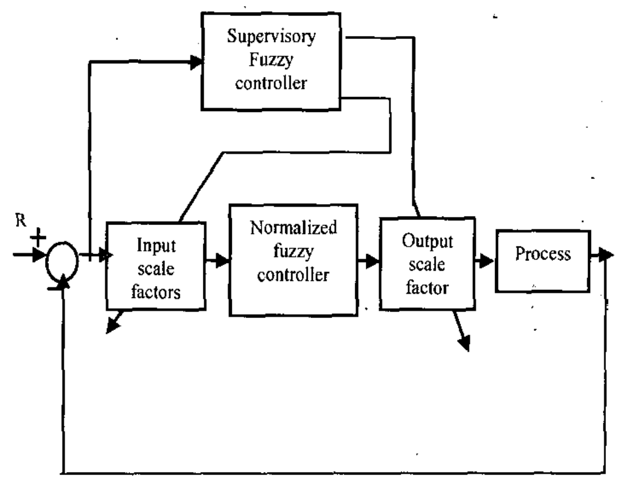


Fig. 2 Over-all Block of the process and supervisory fuzzy controller with the same inout sienal of the main controllers

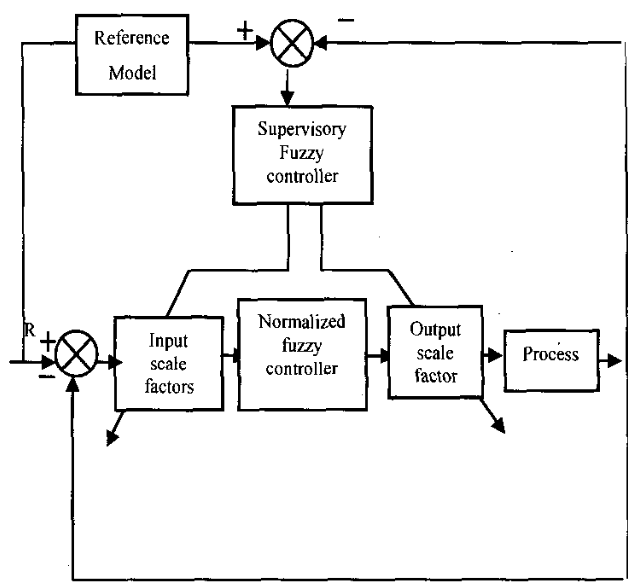


Fig. 3 over-all supervisory fuzzy controller using model reference technique.

3- THERMAL PROCESS AND LEVEL PROCESS HARD-WARE CONFIGURATION

The thermal process is a continuous process. The apparatus consists of an electrically heated model process, conditioning unit and digital controller. The model is an electrically heated aluminum process block surrounded by a water jacket; into which is inserted a platinum resistance thermometer is inserted. The model is designed so that it is, in effect, a speed up version of an industrial process with time constant shortened, to make the experiment of a suitable duration for laboratory work. The control problem investigated is that to maintain the process temperature under variation of heat losses (by variable cooling water flow rate).

The required process temperature (set point) is adjusted by gradual dial on the panel. The error signal is suitably amplified to drive a temperature deviation of 200mv for one degree centigrade of the temperature error change. The control of the power to the process heater is achieved using thyristor circuit operating in burst firing mode, which transforms the control signal of ±10 v from the controller to 0-220V to the heater. The schematic diagram of the process is shown in Fig. 4.

The level process is a continuous process. The apparatus consists of level tank driving pump and two electric valves, one for feedback water and the other for output water flow rate driven by their positioning units. The control problem investigated is that to maintain the tank level constant under variation of output water flow rate. The required process level (set point) is adjusted in the controller. The actual level is measured using level sensor. The level signal is suitably amplified to drive 50mv for one percent of the tank capacity. The controller output signal is 0-5 volt to operate the feedback valve and the feeding pump is supplied from constant 220V AC supply. The schematic diagram of the process is shown in Fig. 5.

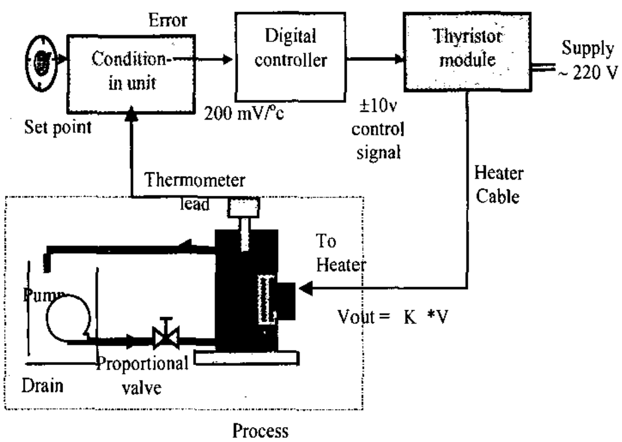
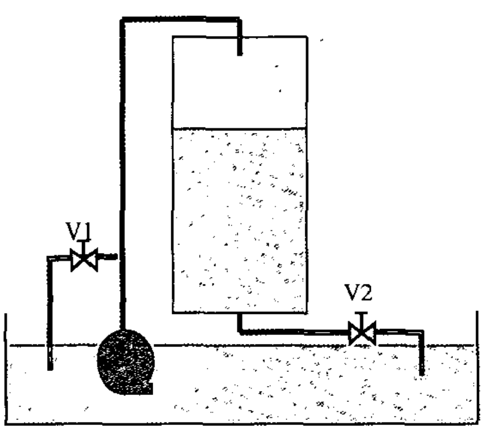


Fig. 4 Schematic diagram of thermal process



Fig, 5 Schematic diagram of level process

The two experimental process tested in this work are a simulation model of two process variable (temperature and level) in actual liquefied petroleum gases recovery process in petrochemical industries. The system is exposed to a variable condition irregularly so the exist controller (mainly PI) not suitable.

4- EXPREMENTAL WORK

The first parameter of the fuzzy logic controller (FLC) was obtained from a manual tuning of process that gave the most appropriate response [16]. Fig. 6 shows the normalized membership function of inputs and outputs signals of the FLC and Table 1 shows the fuzzy rule base. The process response for step input 30°c and 50% flow rate cooling waters and using static fuzzy controller described above is shown in Fig. 7. Using supervisory fuzzy controller to tune the main fuzzy controller output scale factors, with membership function is shown in Fig. 8, and the rule base is shown in Table 2. These parameters are selected according to the experience and manual tuning results. The input signals for both the supervisory controller and the main controller are the same but the output is the new scale factor. The block diagram of the overall control system is shown in Fig. 2. The system response using supervisory controller for step input 50°c and different cooling water flow rates (disturbance case); is shown in Fig. 9 when scale factor for inputs fixed to 10 and 20 respectively. The results show the robustness of the supervisory fuzzy controller

TABLE 1
FUZZY ALLOCATION MATRIX OF NORMALIZED FUZZY CONTROOLER

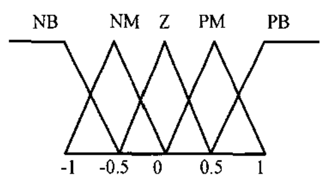


Fig. 6 Normalized membership function of inputs and output variables

e \ Δe	NB	NM	Z	PM	PB
NB	PB	PB	PM	Z	Z
NM	PM	PB	PM	Z	Z
Z	PM	PM	Z	NM	NM
PM	Z	Z	NM	NB	NB
PM	Z	NM	NB	NB	NB

Fig. 10 shows the responses of the supervised system in case of one output scale factor and two outputs (control output and error scale factor) i.e. there are two outputs from the supervised system. The relation between each output from the supervisory controller and its input signal is specified according to the rule base in Table 2. Each output membership functions are taken as shown in Fig. 8 for all outputs. By comparing both results, the system response is improved in case of tuning the input and output scale factors simultaneously, where the overshoot is reduced.

The output gains of the supervised fuzzy controller, in all of the responses obtained, depend on the error signal between the reference input to the process and the actual output. In this case the system response performs accepted specification but if it is desired to force the over-all system to achieve a desired specification such as overshoot, rise time etc... the output gains should be related to that specifications. Model reference adaptive technique Fig. 3 is one of the adaptation methods used to force the system performance to the desired specifications. If the reference output was taken as a second order system with 2% overshoot and 150 sec rise time. Fig.11 shows the forcing of the system for different operating condition of the process 50% and 80% cooling water flow rates. Fig. 12 shows the system response for step input 20°c and different cooling water flow rates (disturbed case). The results show the robustness of the model reference supervisory fuzzy controller. By analysis the results, the supervisory controller improve the system performance, but if it is desired to restrict the performance model reference supervisory controller is preferred.

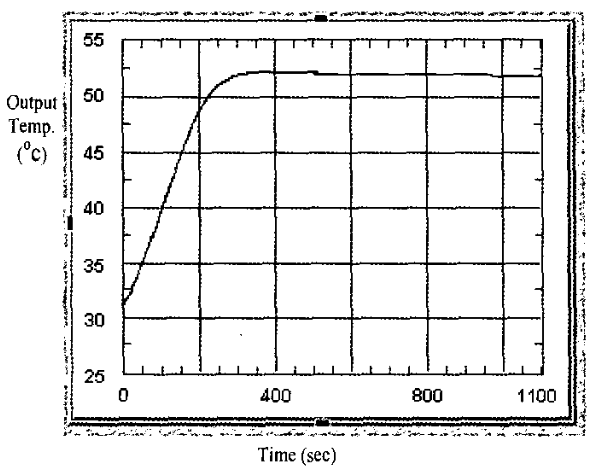


Fig. 7 Normalized fuzzy controller response (without supervision)

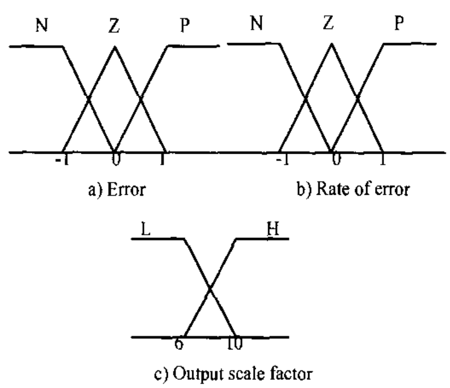


Fig. 8 Input/output membership function of supervisory fuzzy controller

Table 2
FUZZY ALOCCATION MATRIX OF SUPERVISORY FUZZY

e \ Δe	N	Z	P
N	H	H	L
Z	L	L	H
P	L	H	H

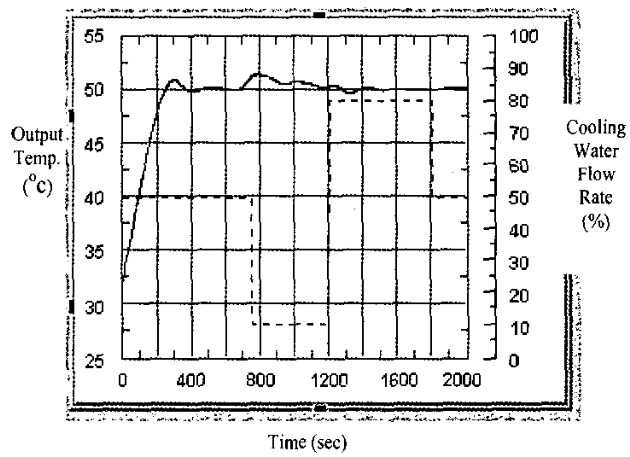


Fig. 9 Output response for distributed system

——— Response

- - - - - - - Cooling water flow rate

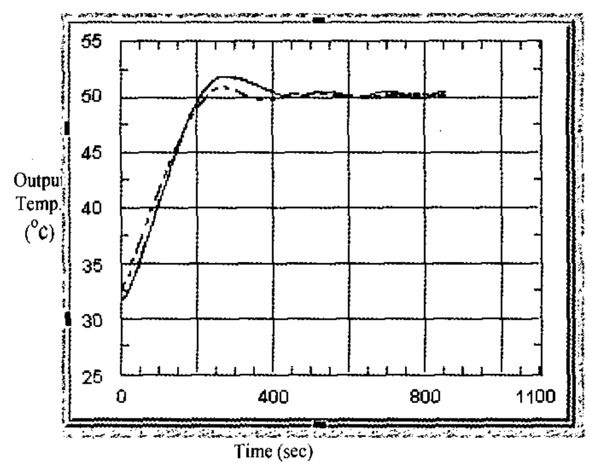


Fig. 10 Response of supervisory controller in case supervising of output-input scale factors and output only

——— Output scale factor supervision

—..—..—. Input-output scale factors supervision

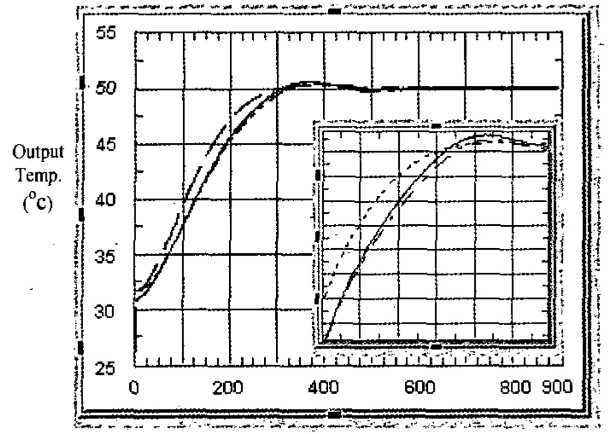


Fig. 11 Model reference supervisory fuzzy controller response for different cooling water flow rate

——— Flow rate 50%

- - - - - - - - Flowrate80%

—·—·—·— Reference model output

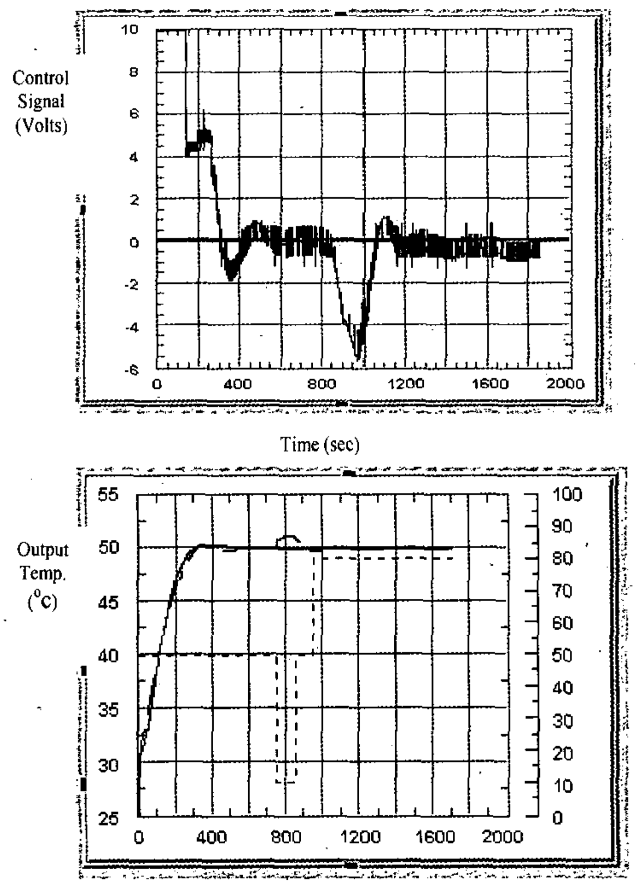


Fig. 12 Control signal and output response for distributed system

——— Desired model output

- - - - - Cooling water flow rate

—·—·· Response

Applying the supervisory fuzzy controller based on the variation of the output response to the level process in Fig. 5 with the same parameter used in the thermal process with changing the controller output to 0-5V corresponding to 0%-100% opening of the feedback valve and the sensor signal level 0-5V corresponding to 0%-100% level. The level response for step input 60% and disturbed suction valve is shown in Fig. 13. The variation of scale factor of input and output of the supervisory controller is shown in Fig. 14. It is no need to apply model reference adaptation technique in this case where the system achieves the best performance with minimum rise time and 0% overshoots.

After testing the supervisory fuzzy controller in thermal and level process without prior information about the level process it is note that supervisory fuzzy controller can be standard controller for different loops (process variables) in DCS system and also can be used for any single input and output process control loop by some changing in the ranges of scales, input and outputs signal limits.

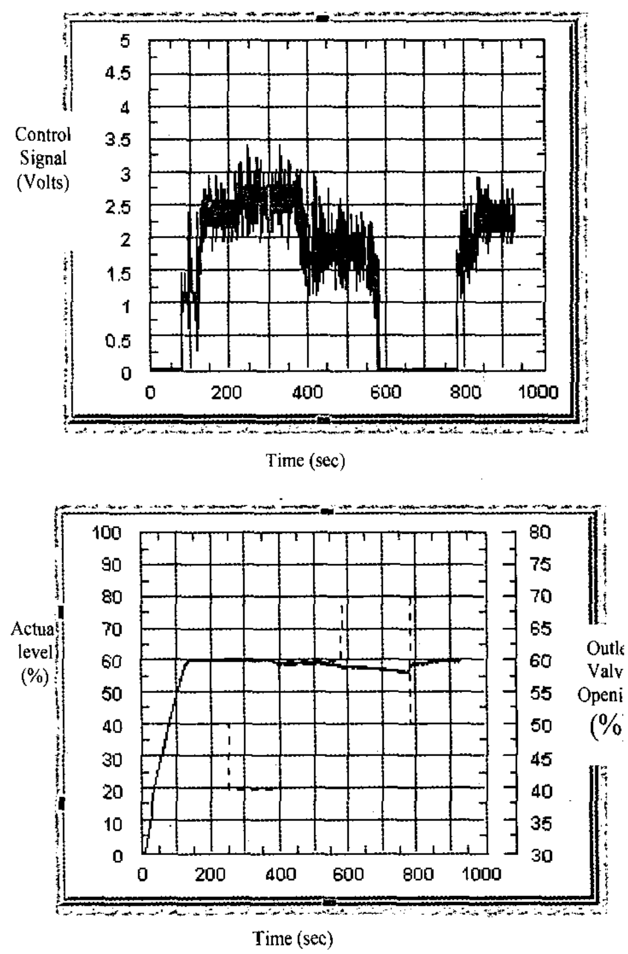


Fig 13 Control signal and actual level with disturbed suction valve

——— Actual level

- - - - - - Percentage opening of suction valve (V2)