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Parallel Distributed Compensator Design For Non Linear Tank

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***Abstract*: In this paper, a fuzzy controller is designed based on parallel distributed compensation (PDC) method. The non linear process considered in this paper is single Cylindrical Tank. Firstly, a mathematical model of the system is obtained mathematically. An important feature of the plant is its nonlinearity. To control the level of water in the tank over the whole range, the nonlinear model of the system is linearized around three different operating points. Then, three PI controllers are designed for the operating points, using Skogestad's method. By using the PDC method, an overall fuzzy controller is designed by the fuzzy blending of the three PI-controllers. The comparison results showed the superiority of the PDC-controller over the classical PI-controller.**

***Keywords:* Parallel Distributed Compensator (PDC), Takagi Sugeno Fuzzy, PI controller.**

I. INTRODUCTION

In many industrial processes, control of liquid level is required. It was reported that about 25% of emergency shutdowns of the nuclear power plant are caused by poor control of the steam generator water level. Such shutdowns greatly decrease the plant availability and must be minimized. Water level control system is a very complex system, because of the nonlinearities and uncertainties of a system. Currently, constant gain PI controllers are used in nuclear organizations for boiler water level control at high power operations. However, at low power operations, PI controllers cannot maintain water level properly. A need for performance improvement in existing water level regulators is therefore needed.

The three important loop attributes are – Set-point Tracking, Disturbance-Rejection and Robustness. The Conventional Control Structure (CCS) with a PID controller is the most commonly used controllers in most of the industry. However, in a Conventional Control Structure, three loop attributes are closely related changing one property may affect the other property. The control engineer has to perform adjustments or tuning of the controller parameters, in order to achieve the desired performance level in one or more of the three attributes after implementation of control structure due to process variability and uncertainty. Therefore, the development of an alternative control structure that allows for Transparent Tuning is significant, by which it is meant that three parameters of the control scheme should directly and independently tune for the three loops attributes. The main aim of this work is to design a Parallel Distributed Compensator with a local linear PI controller as rule consequents for control of level in a tank.

The aim of this paper is to design and implement a fuzzy controller based on the PDC method to control the level of liquid in a tank. Initially, a mathematical nonlinear model for cylindrical tank level control system is obtained. Then, the nonlinear model at three operating points is linearized. Three PI controllers for three equilibrium points are obtained. Since the control objectives are setpoint tracking and disturbance rejection over the whole range of the operation, the three PI controllers should be combined with each other. To combine the three controllers, the PDC technique is used.

This paper is organized as follows: In Section 2, the system is described and the modeling process of the system is presented in Section 3. The PI tuning method, the PDC method and controller design are outlined in Section 4. Section 5 illustrates the simulation results, and finally, Section 6 concludes the paper.

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II. PROCESS DESCRIPTION

In this paper the non linear tank considered is a cylindrical single tank system.

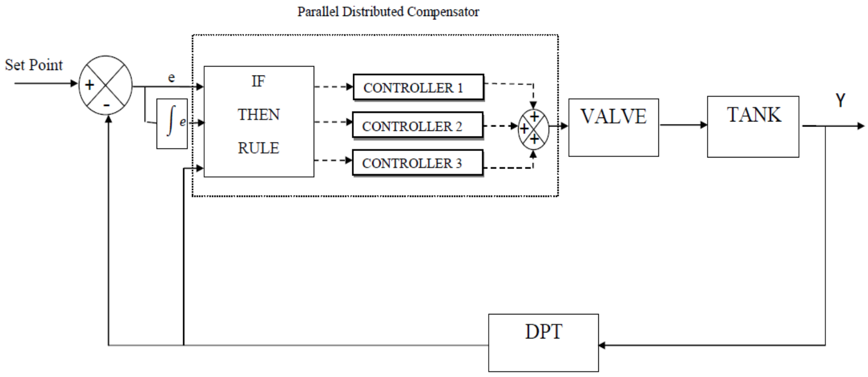

Fig 1. Block Diagram

In the level system the level of the tank is controlled by controlling the flow rate. This is achieved by using the Parallel Distributed Compensator. In this the rules are given by using Takagi-Sugeno fuzzy model and the PDC will blend the whole controller as a single controller.

The tank is fed by water pumped from the reservoir through the control valve. The level of the liquid in the tank is measured by the transmitter level, then, the transmitted signal is sent to the PC via the data acquisition card. The error is computed by subtracting the process output from the desired set point. The controller produces the control signal according to the error. The control signal is sent to the actuator (control valve) via the data acquisition card to change the input flow rate. The control valve is fully closed and fully opened when the command signal from the controller.

III. PROCESS MODELING

Mathematical models can take many forms, including but not limited to dynamical systems, statistical models, differential equations, or game theoretic models. These and other types of models can overlap, with a given model involving a variety of abstract structures. In general, mathematical models may include logical models, as far as logic is taken as a part of mathematics. In many cases, the quality of a scientific field depends on how well the mathematical models developed on the theoretical side agree with results of repeatable experiments.

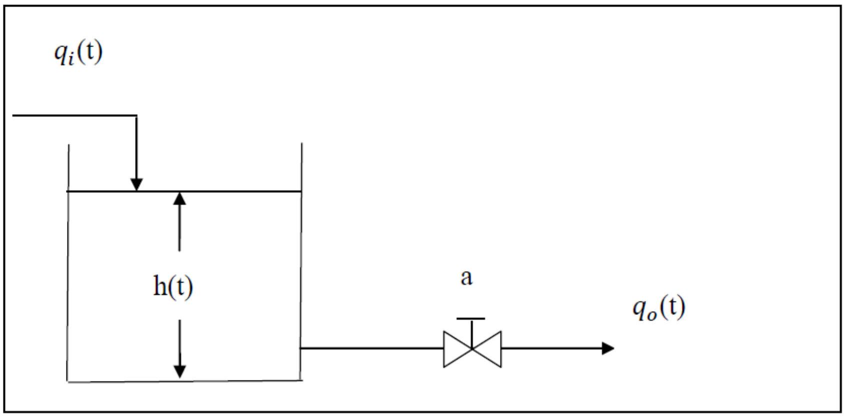

Fig 2. Cylindrical Tank System

Let q_i and q_o be the inflow rate and outflow rate (cm^3/s) of the tank, and h (cm) is the height of the water level at any time instance. The dynamics of the tank are:

$$q_i(t) - q_o(t) = A\frac{dh}{dt} \quad (1)$$

$$q_o(t) = a\sqrt{h} \quad (2)$$

Where A (cm^2) is the cross-section of the tank and a (cm^2) is a parameter related to the position of the outlet valve. After linearization around an equilibrium point, h_s, the corresponding transfer function is obtained as follows:

$$\frac{H(s)}{Q_i(s)} = \frac{R}{T_C s+1} \quad (3)$$

$$R=\sqrt{H}/a\,;\ \frac{\sqrt{H}A}{a} = RA = T_c$$

Note that no time delay is considered in Equation (3). Since there are some lags in the inflow with respect to the controller command, the transfer function would be:

$$\frac{H(s)}{Q_i(s)} = \frac{R}{T_C s+1}e^{-\tau_d s} \quad (4)$$

Where τ_d - time delay

By substituting the values for A as 342.6 cm^2 and a as 5.75 cm^2.

The three operating points are at three different heights: h = 30 cm, h = 50 cm and h = 75 cm.

The transfer functions of the plant around the operating points are as follows.

$$\frac{H(s)}{Q_i(s)} = \frac{0.95}{326.44s+1}e^{-2s} \text{ at h= 30 cm} \quad (5)$$

$$\frac{H(s)}{Q_i(s)} = \frac{1.23}{421.4s+1}e^{-2s} \text{ at h = 50 cm} \quad (6)$$

$$\frac{H(s)}{Q_i(s)} = \frac{1.5}{516.15s+1}e^{-2s} \text{ at h = 75 cm} \quad (7)$$

IV. CONTROLLER DESIGN

As Equations. (1) and (2) show, the system is nonlinear. So to achieve tracking and disturbance rejection, Equation (1) is linearized around three operating points and three PI controllers are designed for these points.

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. To remove the offset integral action is required and so PI control is normally used. It works by summing the current controller error and the integral of all previous errors. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system.

$$u(t) = k_p e(t) + k_i \int e(t)dt \quad (8)$$

A. PI controller using Ziegler Nichols Tuning:

Some of the tuning methods are the Good Gain method, and the Ziegler-Nichols' method. These methods are experimental. That is, they require experiments to be made on the process to be controlled.

The PI controller is designed by using Ziegler Nichols open loop tuning formulas. The controller parameters are given in the table 1.

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Table 1 Controller parameters

Operating range	Z-N tuning		Skogestad tuning	
	K_p	τ_i	K_p	τ_i
0-30 cm	4.56	34.089	4.21	60
31-50 cm	3.53	44.06	3.25	78
51-75 cm	2.89	53.72	2.67	95

B. PI controller using Skogestad PI Tuning:

From [6] The disadvantages in Ziegler Nichols method is it gives poor performance for process with dominant delay and it give good disturbance response whereas in the IMC PID tuning it give poor disturbance response and it give very good response for set point tracking.

For this Level control, the main objective is to handling disturbance rejection and set point tracking. The purpose of using this tuning method is

- It works well for both integrating and pure time delay process and the both set point and load disturbance.
- The tuning rules should be well motivated and preferably model based and analytically derived.
- This method is simple and works well for a wide range of process.

The PI controller is designed by using Skogestad PI tuning formulas. The controller parameters are given in the table 1.

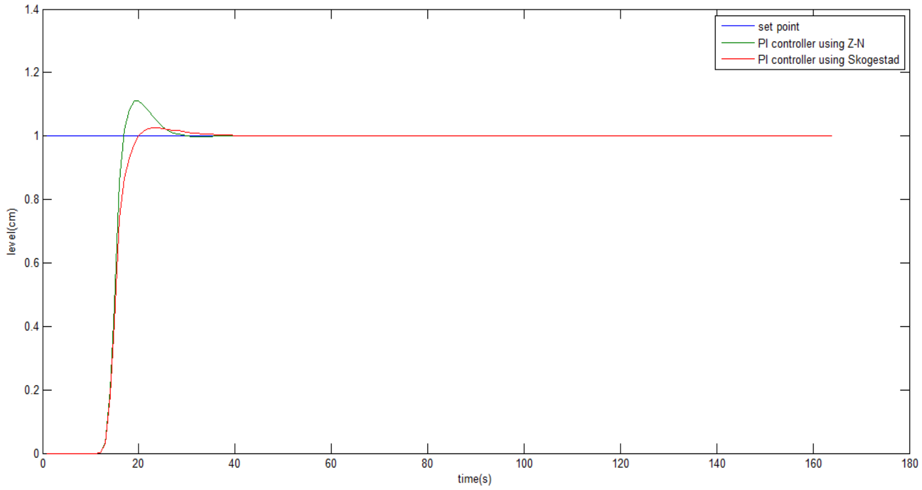

Fig 3 comparison of PI controller using Z-N and Skogestad tuning

From the response the Skogestad tuning PI controller has less overshoot and it settles faster than Ziegler Nichols tuning.

C. Parallel Distributed Compensator:

PDC is an efficient tool for building of process Fuzzy Logic Controller for nonlinear plant with time delay and model uncertainty. PDC offers a procedure to design a fuzzy controller from a given T-S fuzzy model. Most of the nonlinear system can be transformed into the Takagi Sugeno model.

The main idea of PDC technique is to partition the dynamics of a nonlinear system into a number of linear subsystems. Design of a number of local controllers for each linear subsystem and finally generates the overall compensator by the fuzzy blending of such local controllers.

In the PDC design, the controller consists of a set of fuzzy rules. In this method, the dynamics of a nonlinear system are partitioned into a number of linear subsystems.

The fuzzy PDC controller is Sugeno first order type with three input variables and one output variable.

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The controller in this paper is a Takagi Sugeno based one. It uses a rule base in linguistic terms. There are three inputs: error in liquid level, integral of error and measured level and one output parameter: PI controllers. Triangular and Gaussian membership functions are selected to fuzzify the inputs. The ranges of the error and its time derivative (inputs) are set as follows:

e ϵ [-75, +75], *e* (*t*) ϵ [-75, +75] ,θ ϵ [0,75] and u(t) ϵ [-1, +1]

Figure 4 (a) – (c) shows the fuzzification process with y-axis as membership values.

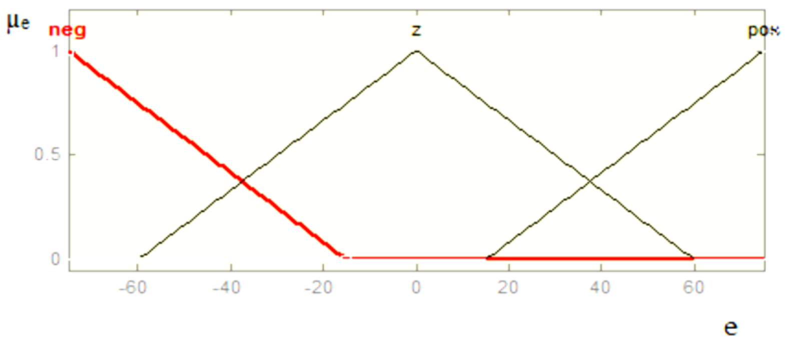

Fig 4 (a) Fuzzification of error e

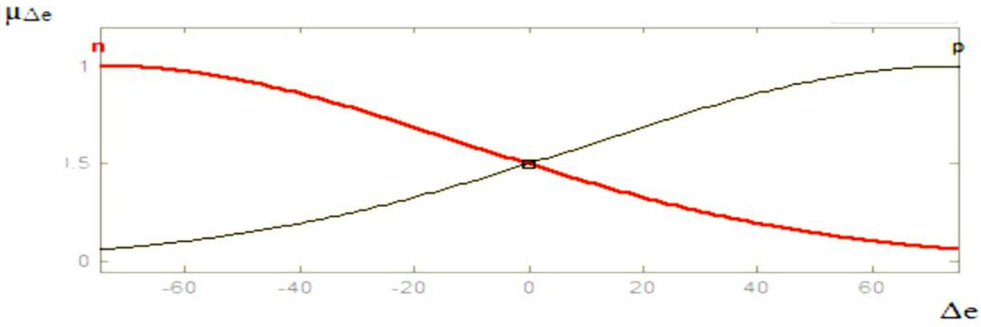

Fig 4 (b) Fuzzification of integral of error Δe

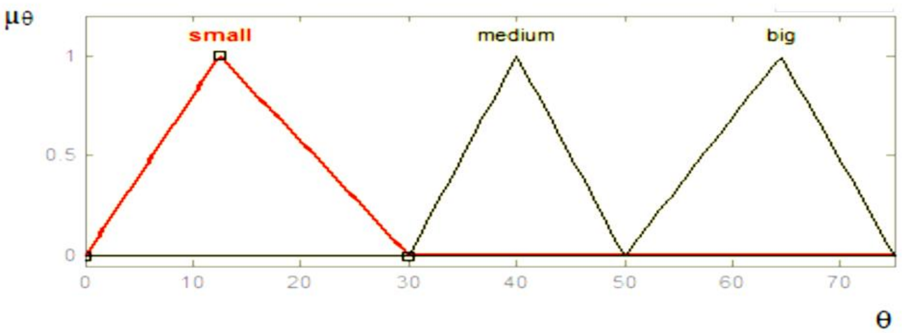

Fig 4 (c) Fuzzification of Level θ

The parameters of the PI controllers for each of the three local linear systems are given in Table 1.

The fuzzy rules after tuning of the local PI controllers are specified to the following groups:

1. **IF** (e is Neg **AND** Δe is N **AND** θ is Small) **THEN** Δu1=2.3.ek +0.02.Δe

2. **IF** (e is Neg **AND** Δe is P **AND** θ is Small) **THEN** Δu1=2.3.ek +0.02.Δe
3. **IF** (e is z **AND** Δe is N **AND** θ is Small) **THEN** Δu1=2.3.ek +0.02.Δe
4. **IF** (e is z **AND** Δe is P **AND** θ is Small) **THEN** Δu1=2.3.ek +0.02.Δe
5. **IF** (e is pos **AND** Δe is N **AND** θ is Small) **THEN** Δu1=2.3.ek +0.02.Δe
6. **IF** (e is pos **AND** Δe is P **AND** θ is Small) **THEN** Δu1=2.3.ek +0.02.Δe
7. **IF** (e is Neg **AND** Δe is N **AND** θ is Med) **THEN** Δu2=1.8.ek +0.013.Δe
8. **IF** (e is Neg **AND** Δe is P **AND** θ is Med) **THEN** Δu2=1.8.ek +0.013.Δe
9. **IF** (e is Z **AND** Δe is N **AND** θ is Med) **THEN** Δu2=1.8.ek +0.013.Δe
10. **IF** (e is Z **AND** Δe is P **AND** θ is Med) **THEN** Δu2=1.8.ek +0.013.Δe
11. **IF** (e is Pos **AND** Δe is N **AND** θ is Med) **THEN** Δu2=1.8.ek +0.013.Δe
12. **IF** (e is Pos **AND** Δe is P **AND** θ is Med) **THEN** Δu2=1.8.ek +0.013.Δe
13. **IF** (e is Neg **AND** Δe is N **AND** θ is Big) **THEN** Δu3=1.5.ek +0.01.Δe
14. **IF** (e is Neg **AND** Δe is P **AND** θ is Big) **THEN** Δu3=1.5.ek +0.01.Δe
15. **IF** (e is Z **AND** Δe is N **AND** θ is Big) **THEN** Δu3=1.5.ek +0.01.Δe
16. **IF** (e is Z **AND** Δe is P **AND** θ is Big) **THEN** Δu3=1.5.ek +0.01.Δe
17. **IF** (e is Pos **AND** Δe is N **AND** θ is Big) **THEN** Δu3=1.5.ek +0.01.Δe
18. **IF** (e is Pos **AND** Δe is P **AND** θ is Big) **THEN** Δu3=1.5.ek +0.01.Δe

The proposed control algorithm can easily be released in a Simulink model and incorporated in the real time application of MATLAB for future real time control.

V. SIMULATION AND PERFORMANCE ANALYSIS

Fig 5 shows the Simulink block diagram of the PDC and PI controller. The fuzzy inference system was implemented in this fuzzy logic controller and simulated to get the response of the controller to the given parameters.

As seen from the figure, compared with PI control program, the overshoot δ is less in fuzzy curve. Settling time reduces.

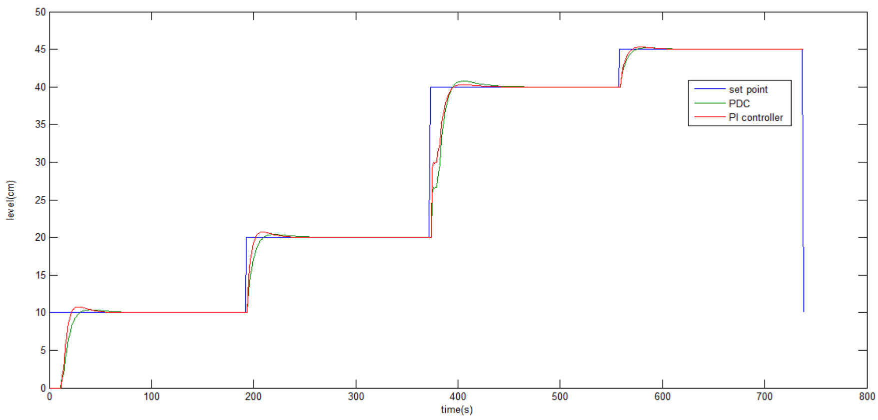

Fig 5 Comparison of PI and PDC

The result of the simulation shows that as far as no balance and complex mathematical models, such a fuzzy control is similar to the human way of thinking. And it is suitable for coarse control at the beginning of the operation to rapidly control. And in order to get better control accuracy, the PI control program used as a fine tune. On the other hand, the

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PDC control program presented has a wide practical value because of the fuzzy control program does not rely on the mathematical model. It can be tried with a fuzzy controller, which generates the rule base based on the PI scheme. An optimized PDC by tuning the fuzzy parameters may be employed to get better accuracy.

VI. CONCLUSION AND FUTURE SCOPE

In this work, the Parallel Distributed Compensator was designed to control the level of the cylindrical tank process using the Takagi Sugeno Fuzzy method. Different controllers which include conventional PI controller using Ziegler Nichols tuning, PI controller using Skogestad tuning and Parallel Distributed Compensator were implemented and their performance was analyzed. By comparing their main performance indices such as set point tracking and Disturbance rejection it is found that Parallel Distributed Compensator exhibits better performance. The results and comparison confirm the high performance of the designed controller based on the PDC.

To prove the performance of the designed controller based on the PDC, the controller was implemented in an experimental setup. The system can be implemented in real time by interfacing LabVIEW.

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