

Real Time Implementation of Parallel Distributed Compensator design for Non Linear Tank

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Abstract— In this paper, Parallel Distributed Compensator (PDC) method is designed and implemented in a nonlinear process. The non linear process considered in this paper is single Cylindrical Tank. Firstly, the system is obtained using System Identification. A paramount feature of the plant is its nonlinearity. To control the level of water the nonlinear model of the system is linearized around two different operating points. Then, two PI controllers are designed for the operating points, using Skogestad's tuning method. The examination results demonstrated the predominance of the PDC-controller over the traditional PI-controller.

Index Terms—Parallel Distributed Compensator (PDC), PI controller, LabVIEW, Takagi Sugeno Fuzzy.

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.

In this regard, some benchmark level control systems have been developed in the literature, e.g., one, three and four tank system. Various fuzzy PI-like controllers have been designed – incremental two inputs with supervisory fuzzy Autotuning [1]. Most of them have been tested not only by simulation [2] but also in real time control.

We have witnessed a rapidly growing interest in fuzzy controllers in recent years. Fuzzy logic has many varieties to be implemented for control purposes. One of

them is parallel distributed compensation (PDC). The PDC offers the procedure to design a fuzzy controller from a given Takagi-Sugeno (T-S) fuzzy model. Most of the nonlinear systems can be transformed into the T-S fuzzy model[3].

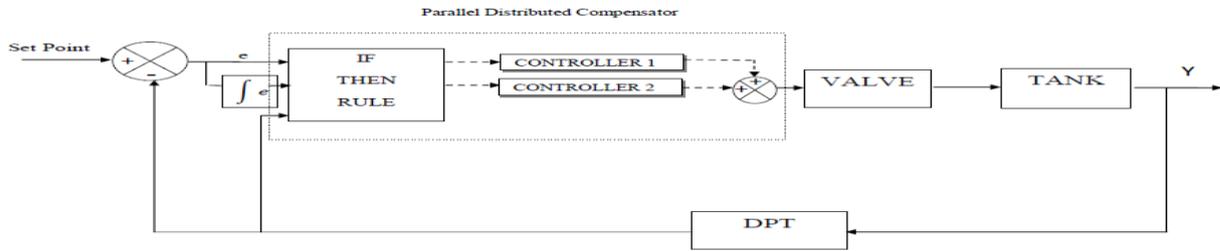
PDC has been used for solving varieties of control system problems. The T-S fuzzy model of a pendulum is obtained and a proper PDC is designed in [4]. A method called ARPDC for automatic control of nonlinear systems is introduced in [5]. Ref. [6] Introduces the design and implementation of a two-wheel inverted pendulum via the PDC.

The main aim of this paper is to design a Parallel Distributed Compensator with a local linear PI controller as rule consequents for control of level 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 process is described and the process model is presented in Section 3. The PI tuning method, the PDC method and controller design are outlined in Section 4. Section 5 illustrates the results, and finally, Section 6 concludes the paper.

II.PROCESS DESCRIPTION

The overall process is shown in fig.1. 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.



DPT – Differential Pressure Transducer

Fig 1. Block Diagram

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 control valve via the data acquisition card to change the input flow rate. The control valve is fully closed or fully opened that will depend on the command signal from the controller. The controller program is fed by using LabVIEW program.

III.PROCESS MODELING

System identification is the process of developing or improving the mathematical representation of a physical system using experimental data. The primary objective of system identification is to determine the plant parameters from measured/analyzed data often with noise. The model parameters are computed from the system data. The system

identification is done by interfacing the tank using Data Acquisition Card with LabVIEW.

The tank is a nonlinear system whose time constant and gain vary considerably throughout the operating range. The controlled variable is the liquid and the control variable is the inlet flow rate with flow range between 0 to 1000 lph. The outlet flow varies due to liquid height level. The nonlinearity of the tank is split into two regions to linearise at certain equilibrium points. By doing the system identification the two non linear region is found out. While giving the step input of 2 V the level will reach the maximum range of 68 cm. Beyond that there is no possibility of non linearity. Dynamic characteristics are described by following first order differential equation.

The general 1st order transfer function is

$$G(s) = \frac{K_p}{\tau_c s + 1} e^{-t_d s} \tag{1}$$

Where,

Plant gain (K_p) = $\frac{\text{change in output}}{\text{change in input}}$

Time constant (τ_c) - 63.2 % of steady state value

Time delay (t_d) – input output lag

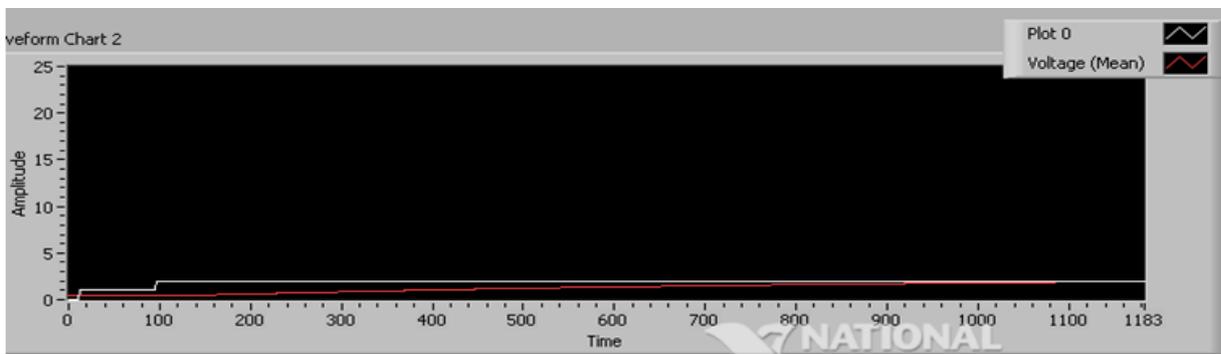


Fig 2 System identification response

From the fig 2. the parameters such as K_p , τ_c . The transfer function is tabled in the table shown below.

Table 1 Transfer function of the plant for two regions

S.No	Region (cm)	Transfer function
1	0-35	$G(s) = \frac{1.029}{352.6s+1}$
2	36-70	$G(s) = \frac{1.456}{498.65s+1}$

IV. CONTROLLER DESIGN

The system is nonlinear. So to achieve tracking and disturbance rejection, the system is linearized around two operating points and three PI controllers are designed for these points.

PI controller will wipe out forced oscillations and steady state error resulting from 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 an integral mode has a negative essence on speed of the response and overall stability of the system.

$$u(t) = k_p e(t) + k_i \int e(t) dt \tag{2}$$

where,

k_p : Proportional gain, a tuning parameter

k_i : Integral gain, a tuning parameter

e : Error = SP – PV

t : Time or instantaneous time (the present)

A. PI controller using Ziegler Nichols Tuning

The PI controller is designed by using Ziegler Nichols open loop tuning formulas. 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 controller parameters are given in the table 2.

The formulas [7] used for finding the controller parameters, controller gain (K_c) and Integral time constant (τ_i) using Z-N tuning methods are as follows:

$$K_c = \frac{0.9 T}{t_d K_p} \tag{3}$$

$$\tau_i = 3.3 t_d \tag{4}$$

where,

T- Time constant

t_d - Time delay

K_p – Plant gain

Table 2 Controller parameters

Operating range	Z-N tuning		Skogestad tuning	
	K_p	τ_i	K_p	τ_i
0-35 cm	4.56	34.089	4.21	60
36-70 cm	3.53	44.06	3.25	78

B. PI controller using Skogestad PI Tuning

From Ref. [8] The disadvantages of the 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

- This method is simple and 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, preferably model based, analytically derived and works well for a wide range of process.

The formulas [8] used for finding the controller parameters ,controller gain (K_c) and Integral time constant (τ_i) using Skogestad methods are as follows:

$$K_c = \frac{1}{k} \frac{\tau_1}{\tau_c + \theta} \tag{5}$$

$$\tau_i = \min\{\tau_1, 4(\tau_c + \theta)\} \tag{6}$$

Where,

k - plant gain

τ_1 - lag time constant

θ - time delay(dead time)

τ_c -tuning parameter

The controller parameters are given in the table 2.

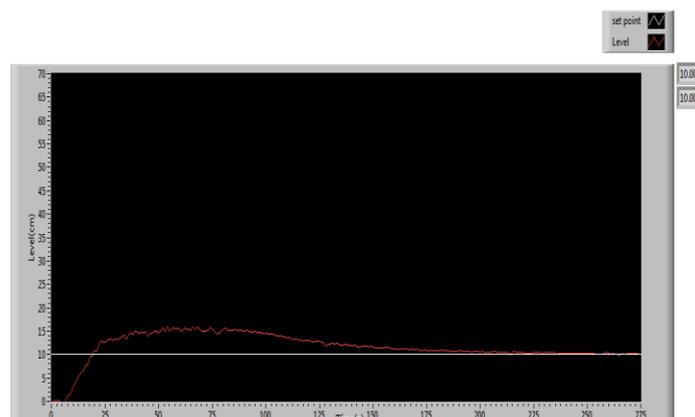


Fig 3.1 Response of PI controller using Z-N tuning

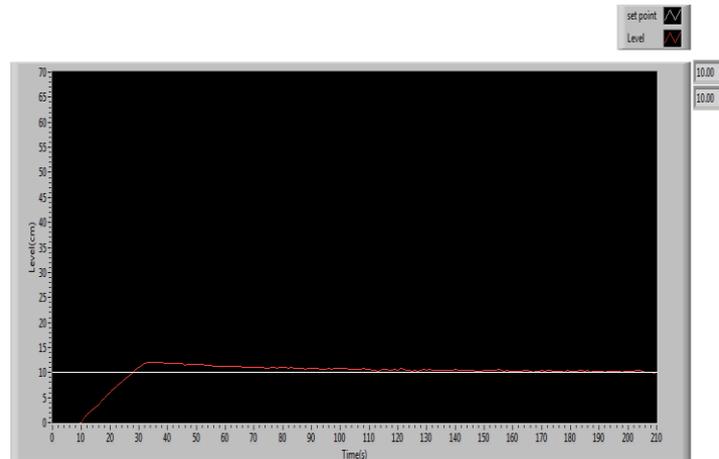


Fig 3.2 Response of PI controller using Skogestad tuning

In the figure shown above the left one is the response of PI controller using Z-N tuning and the right one is the other tuning method. From the response shown in fig. 3.1 and 3.2 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 [9,10] 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 overall fuzzy controller F is as follows:

$$F = \frac{\sum_{i=1}^r w_i(z(t))F_i}{\sum_{i=1}^r w_i(z(t))} = \sum_{i=1}^r h_i(z(t))F_i \quad (7)$$

Where,

$$z(t) = [z_1(t) z_2(t) \dots z_p(t)]$$

$$w_i(t) = \prod_{j=1}^p M_{ij}(z_j(t))$$

$$h_i(z(t)) = \frac{w_i(z(t))}{\sum_{i=1}^r w_i(z(t))}$$

For all t and $M_{ij}(t)$ is the grade of membership of z_j in M_{ij} .

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

$$e(t) \in [-75, +75], \Delta e(t) \in [-75, +75], \theta \in [0, 75] \text{ and } u(t) \in [-1, +1]$$

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

Control Rule 1 : IF h(t) is about 25cm, THEN the controller is F_1 .

Control Rule 2 : IF h(t) is about 50cm, THEN the controller is F_2 .

where $F_i = K_{Pi} + K_{Ii}/s$ are PI controllers.

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

V.RESULTS AND PERFORMANCE ANALYSIS

As seen from the fig. 4, compared with the PI controller response in fig 3.2, the overshoot δ is less in fuzzy curve and settling time reduces.

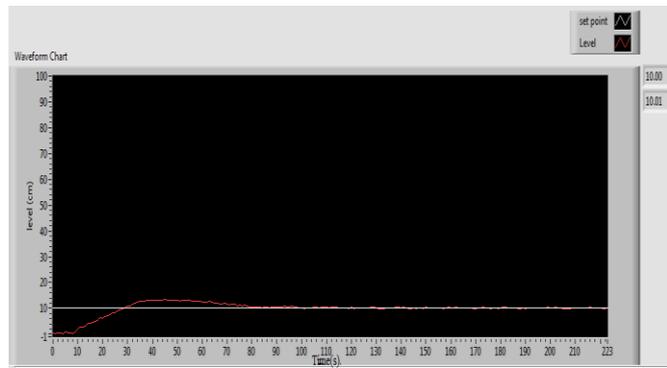


Fig 4 Response of PDC

The result 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 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.

Now, the setpoint tracking problem is evaluated. The input to the Parallel Distributed Compensator and PI controller is given. So that that setpoint given is 10,20,30.

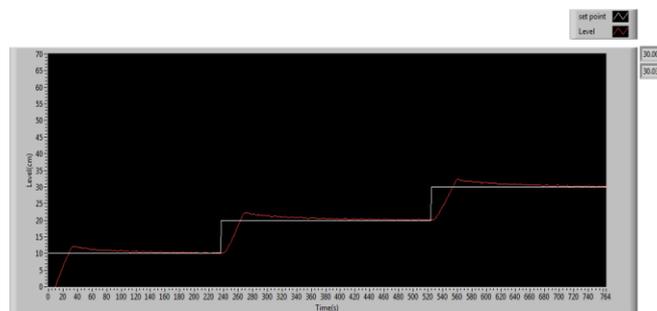


Fig 5.1 Set point tracking: PI

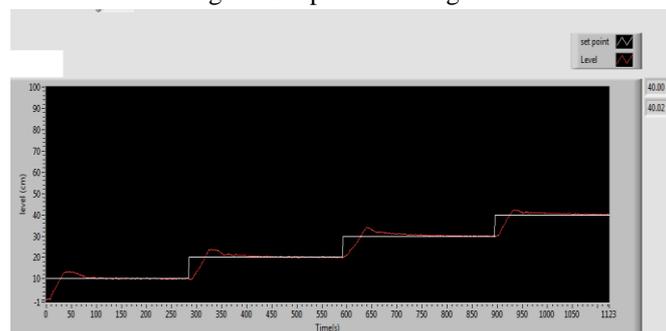


Fig 5.2 Set point tracking: PDC

When different setpoint has been selected, then the servo and regulatory response has been given in Fig. 5.1 and 5.2. In this the PDC tracks the set point faster than the PI controller.

Now, the disturbance rejection problem is evaluated. When the process is in a steady state, suddenly open the outlet valve more, as a step disturbance.

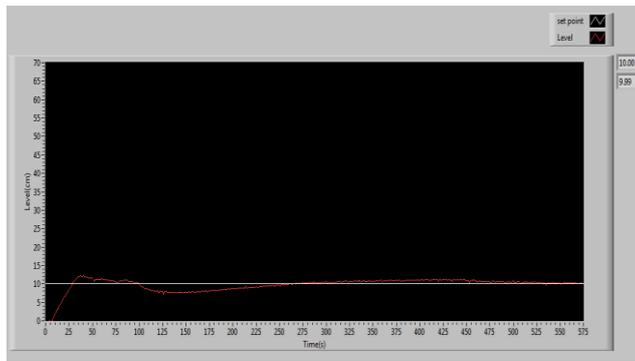


Fig 6.1 Disturbance rejection: PI

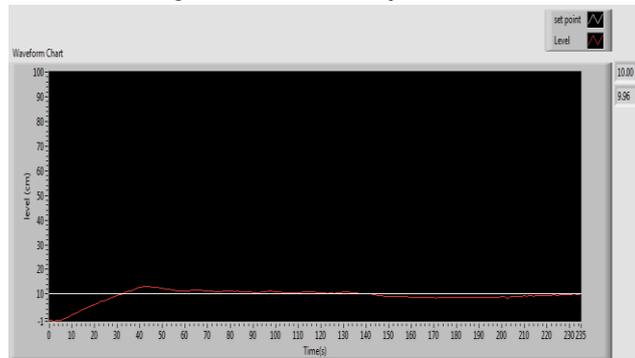


Fig.6.2 Disturbance rejection: PDC

Fig 6.1 and 6.2 shows the disturbance rejection response of two controllers. The fuzzy controller based on the PDC has rejected the disturbance completely in 80s and the PI controller in 275s.

Time domain specifications such as settling time, rise time and overshoot, performance indices such as ISE,

IAE for PI, and PDC are tabulated in Table 3. From that table it is clear that the PDC shows better response in terms of rise time and settling time. The ISE and IAE values are small when PDC is used. PDC controller performance is more satisfactory when compared to PI controller.

TABLE 3 Comparison of Controllers

PERFORMANCES	PI USING Z-N TUNING	PI USING SKOGESTAD TUNING	PARALLEL DISTRIBUTED COMPENSATOR
Rise time (s)	50	32	45
Settling time (s)	210	135	78
Overshoot	7	3	2
ISE	903.81	226.73	58.48
IAE	30.06	15.05	7.64

VI.CONCLUSION AND FUTURE SCOPE

In this paper, the Parallel Distributed Compensator was designed and implemented to control the level of the cylindrical tank process. 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.

Future works will deal with the application of the PDC approach to other nonlinear process control systems such as spherical tank, conical tank and coupled tank systems.

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