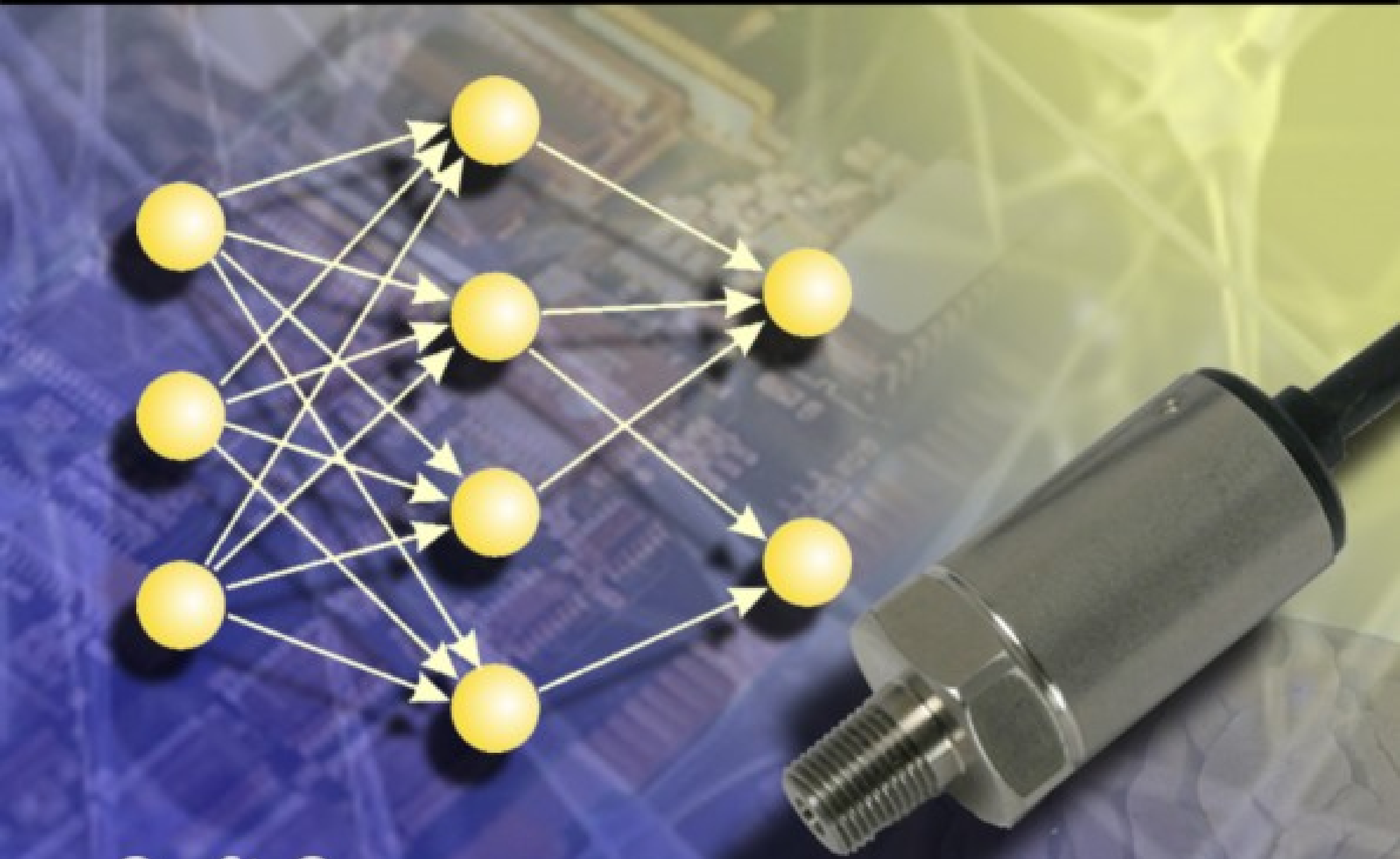
ISSN 1726-5479

SENSORS & TRANSDUCERS

10/08 vol. 97



Soft Sensors and Artificial Neural Networks

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Volume 97
Issue 10
October 2008

www.sensorsportal.com

ISSN 1726-5479

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA).
Available in electronic and CD-ROM.

Sensors & Transducers Journal

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Volume 97
Issue 10
October 2008

www.sensorsportal.com

ISSN 1726-5479

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Sensors & Transducers Journal, Vol. 97, Issue 10, October 2008, pp. 34-44

Sensors & Transducers

www.sensorsportal.com

ISSN 1726-5479

http://www.sensorsportal.com

Performance of Globally Linearized Controller and Two Region Fuzzy Logic Controller on a Nonlinear Process

[1]N. Jaya, [2]D. Sivakumar, [3]R. Anandanatarajan
[1,2]Department of Electronics & Instrumentation Engineering,
Faculty of Engineering & Technology, Annamalai University, Annamalainagar, 608002
Tamilnadu, India
[3]Department of Electronics & Instrumentation Engineering, Pondicherry Engineering College,
Pondicherry, India
E-mail: jayaramesh75@yahoo.co.in, jayanavaneethan@rediffmail.com

Received: 12 September 2008 /Accepted: 22 October 2008 /Published: 31 October 2008

Abstract: In this work, a design and implementation of a Conventional PI controller, single region fuzzy logic controller, two region fuzzy logic controller and Globally Linearized Controller (GLC) for a two capacity interacting nonlinear process is carried out. The performance of this process using single region FLC, two region FLC and GLC are compared with the performance of conventional PI controller about an operating point of 50 %. It has been observed that GLC and two region FLC provides better performance. Further, this procedure is also validated by real time experimentation using dSPACE. *Copyright © 2008 IFSA.*

Keywords: Nonlinear control, GLC, Two capacity interacting process, Fuzzy logic controller, dSPACE

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1. Introduction

The traditional and easiest approach to the controller design problem for nonlinear systems involves linearizing the modeling equation around a steady state and applying linear control theory results. It is obvious that the controller performance in this case will deteriorate as the process moves further away from the steady state around which the model is linearized. Apart from the local linearization approach, there are a few other special-purpose procedures which can directly be used to design controllers for nonlinear processes. However, these usually have limited applicability and are often based on accumulated experience with a specific type of nonlinear systems [1]. Recently, fuzzy logic controllers have been successfully applied to a wide range of industrial processes as well as consumer products, and show certain advantages over the conventional PID controllers. Most of the works found in literature use control error (e) and change of the control error (Δe) as inputs. Using only these inputs, the fuzzy controller is not able to identify in which region the process operates. Therefore, such a fuzzy controller cannot make a control action based on the knowledge of the process nonlinearity associated with different regions. In this paper, a two region fuzzy logic controller that uses auxiliary variable is used to indicate in which region the process is operating. Such fuzzy logic controller can compensate for process nonlinearity so that the control performance can be made more uniform throughout different nonlinear regions [2].

The design of controller based on the variable transformation for first order nonlinear process with dead time is presented by Anandanatarajan [3]. But it is not yet extended for higher order processes. Both Globally linearized Controller (GLC) and multi region Fuzzy logic Controller (FLC) presented by Anandanatarajan [3] and Joe Qin [2] respectively are implemented for first order nonlinear process with dead time. In this work, both GLC and FLC are extended to a second order interacting nonlinear process.

2. Experimental Setup

According to Fig. 1, the mathematical model [4] of the two capacity interacting level process considered for study is expressed as

$$q_{in} - \beta_{12} a_{12} \sqrt{2g(h_1 - h_2)} = A\frac{dh_1}{dt} \quad (1)$$

$$\beta_{12} a_{12} \sqrt{2g(h_1 - h_2)} - \beta_2 a_2 \sqrt{2gh2} = A\frac{dh_2}{dt}\ , \quad (2)$$

where β_{12} and a_{12} are the outflow valve coefficients; A is the area of the tank; β_2 is the valve ratio at the outlet of tank 2; and a_2 is the valve ratio between tank 1 and tank 2; q_{in}, h_1, h_2 are the inflow rate, levels of tank1 and tank2 respectively; g is the gravitational constant [5]. The steady state operating conditions and parameters of the process are given in Tables 1 and 2 respectively [6].

Fig. 1. Experimental Setup of Two Capacity Interacting Nonlinear Level Process.

Table 1. Specifications of Experimental Setup.

Level h_1; cm	46.8
Level h_2; cm	24.6
Inflow q_{in} ; lph	170
Area of the tanks A; m^2	0.0154
Valve ratio β_{12}	1.0
Valve ratio β_2	0.9499
Cross sectional area of jointed pipes a_{12},a_2 ; m^2	5e-5
Gravitational constant g; m/sec^2	9.81

3. Design of Globally Linearized Controller (GLC)

A single-input, single-output nonlinear system whose model is given by

$$\frac{dx}{dt} = F(x, u(t - T_d)), \tag{3}$$

where $F(.)$ is an arbitrary nonlinear function of x, the system state variable and u, the control variable in the process. Now it is always possible to separate out the part of this function of x, and x alone; let this be $c_1 f_1(x)$. Then $F(x,u)$ may always be represented as:

$$F(x,u) = c_1 f_1(x) + c_2 f_2(x, u(t - T_d)), \tag{4}$$

where both f_1 and f_2 are taken to be nonlinear, and no restrictions are placed on their functional forms; c_1 and c_2 are constants. Thus the process model can be written as:

$$\frac{dx}{dt} = c_1 f_1(x) + c_2 f_2(x, u(t - T_d)) \tag{5}$$

Now consider the transformation:

$$z = g(x), \tag{6}$$

where $g(.)$ is a function of x alone, to be determined such that the process model equations (3) or (5), which is nonlinear in the original variables x and u, is mapped to model that are linear in z and v.

$$\frac{dz}{dt} = a + bv \tag{7}$$

By differentiating equation (4) with respect t,

$$\frac{dz}{dt} = \frac{dg}{dx} \cdot \frac{dx}{dt} \tag{8}$$

and introducing equation (4) into equation (6), we have

$$\frac{dx}{dt} = c_1 f_1(x) \frac{dg}{dx} + c_2 f_2(x, u(t - T_d)) \frac{dg}{dx} \tag{9}$$

Observe now that if the function $z = g(x)$ to be chosen such that

$$c_1 f_1(x)\frac{dg}{dx} = a \tag{10}$$

$$c_2 f_2(x, u(t - T_d))\frac{dg}{dx} = bv \tag{11}$$

and the nonlinear system is mapped to

$$\frac{dz}{dt} = a + bv \tag{12}$$

In the two capacity interacting nonlinear process, the controlled variable of interest is h_2 and the manipulated variable is q_{in}. Subtracting equation (2) from (1),

$$A\frac{dl}{dt} = u - 2\beta_{12}a_{12}\sqrt{2gl} + \beta_2 a_2\sqrt{2gh_2}\ , \tag{13}$$

where $l = h_1$-h_2 and $u = q_{in}$.

Observe that in accordance with equation (4),

$$f_1(l) = \sqrt{2gl}\ ;\ c_1 = \frac{-2\beta_{12}a_{12}}{A} \tag{14}$$

$$f_2(l,u) = u + \sqrt{2gh_2}\ ; c_2 = \frac{1}{A} + \frac{\beta_2 a_2}{A} \tag{15}$$

From (10), *g(.)* is required to be chosen such that

$$\frac{dg}{dl} = \frac{k_1}{\sqrt{2gl}}\ , \tag{16}$$

where $k_1 = \frac{a}{c_1}$ and by direct integration the required *g(.)* is given by

$$g(l) = \int \frac{k_1}{\sqrt{2gl}} \tag{17}$$

From equation (11), the control implementation law is obtained as

$$f_2(l,u) = k_2 v f_1(l) \tag{18}$$

$$u + \sqrt{2g}h_2 = k_2 v\sqrt{2gl} \tag{19}$$

The transformation g(.) maps the nonlinear system represented by equations (1) and (2) into a linear system as shown in Fig. 2. The transformed system is a linear *pseudo system*, whose mathematical model is

$$\frac{dz}{dt} = a + bv \tag{20}$$

The values of a and b are assumed as –0.7657 and 0.0177 respectively. Mathematically there are no restriction on the values of a and b.

The transfer function of equation (20) is

$$G(s) = \frac{b}{s} \tag{21}$$

The forward path transfer function of the closed –loop system with a PI controller is

$$G_f(s) = \frac{bk_c}{s}\frac{(1+T_i s)}{T_i s} \tag{22}$$

T_i and K_c can be obtained by assuming a closed-loop time constant and damping factor [5]. Interestingly, the tuning parameters are independent of local time constant and local gain of the process.

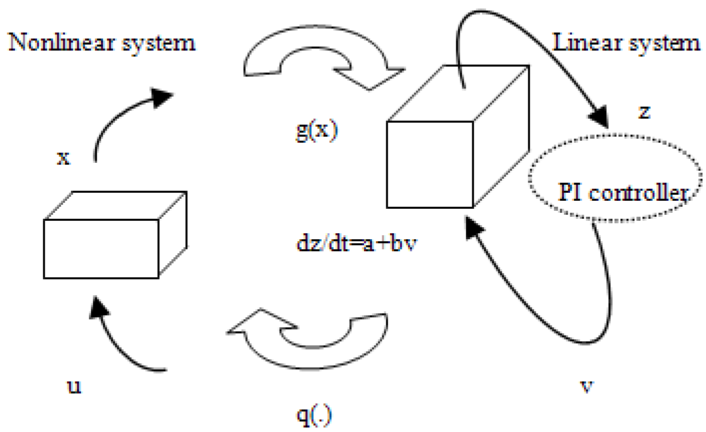

Fig. 2. Conceptual configuration of GLC.

4. Single Region and Two Region Fuzzy logic Controllers

Most industrial processes demonstrate considerable nonlinearity with respect to different regions of operation. It is very difficult to design a fuzzy logic controller for this characteristic by using only the control error and change in the control error. A two region fuzzy controller as shown in Fig. 3 that uses an auxiliary variable is used so as to allow designing of control strategies in different regions. In addition to using control error and change in the control error as inputs, an auxiliary variable is used as another input to determine in which region the process is operating. The functional relationship represented by such a controller can be described as follows:

$$\Delta u = FLC(\Delta e, e, AV), \tag{23}$$

where *FLC(.)* stands for the nonlinear relationship of the fuzzy controller. The auxiliary variable (AV) can be the process input (u_k) or the process output (y_k) depending on how the operation regions are defined. In this case, the auxiliary variable (AV) is the process output y_k .

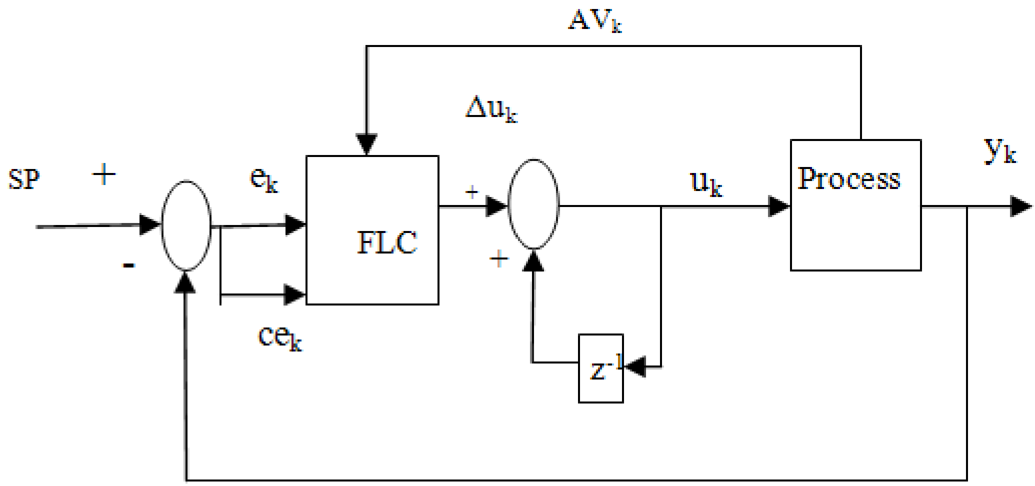

Fig. 3. Block diagram of FLC with auxiliary Variable.

4.1. Rule Definition

A general fuzzy inference rule for the two region fuzzy controller can be described as follows:

If AV is Ai and e is Bi and Δe is Ci then make Δu Di , (24)

where A_i, B_i, C_i and D_i are adjectives for *AV, e.* Δe and Δu respectively. With a two region fuzzy controller using 7 adjectives, a total of 147 rules are resulted.

5. Simulation Results

The (mathematical) model of the process based on variable transformation and fuzzy logic are developed and the suitable controllers are designed using SIMULINK. The responses are compared with a conventional PI controller tuned about operating point of 50 %. The time constant, time delay and gain of the linearized model are 115.86 s, 94 s and 1.492. By applying Ziegler-Nicols (ZN) tuning method [7] the PI controller settings are obtained as proportional gain, K_c=0.83165 and integral time T_i=598.3986 s. Similarly the tuning parameters for GLC using pole placement technique [7] are K_c=0.2824 and T_i=390.3218 s.

The simulation is carried out by taking 50 % as nominal level. The ZN-PI controller, Globally linearized controller, single region FLC and two region FLC are implemented on the two capacity interacting nonlinear level process through simulation and experimentation, the respective servo and regulatory responses are obtained. Further, the robustness of the controllers are tested by obtaining the servo and regulatory responses for operating points of 35 % and 70 % when the controller is tuned at 50% nominal level. The Integral Square Error (ISE) values are presented in the Tables 2-4. It is observed from Fig. 4 that for a 15 % increase in load at nominal operating point 50 % show that the controller based on variable transformations (GLC) gives an improved performance (53 % lesser ISE) than the ZN-PI controller while the two region FLC (39 % lesser ISE) and single region FLC (19 % lesser ISE) also provides better performance than the ZN-PI controller.

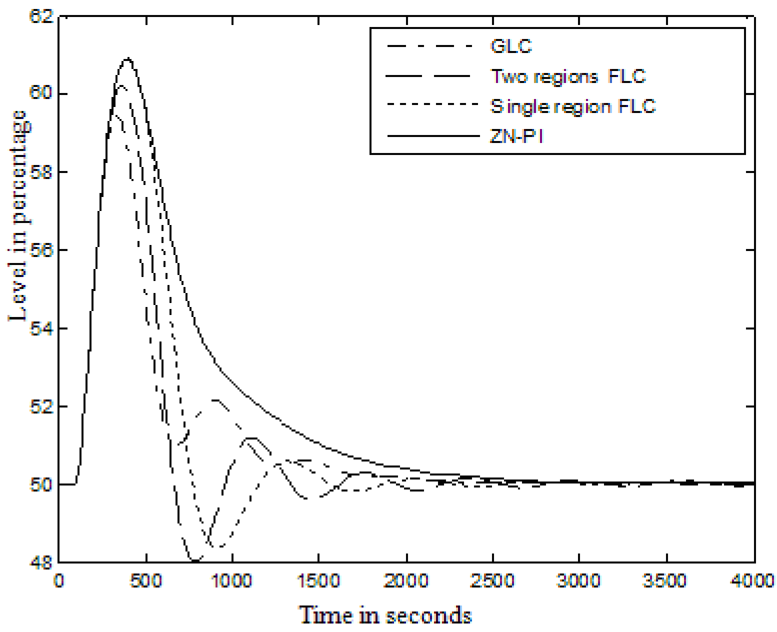

Fig. 4. Regulatory responses for a 15 % increase in load at 50 % nominal operating point.

Table 2. ISE of Regulatory Responses for 15% increase in load.

Operating point	ZN-PI	Single Region FLC	Two Region FLC	GLC
50 %	45770	37440	28050	21900
35 %	40840	28050	24610	19790
70 %	50980	46020	33660	24340

Regulatory responses for a 15 % decrease in load at nominal operating point 50 % (refer to Fig. 5) show that the GLC improves the response (58 % lesser ISE) while the two region FLC (38 % lesser ISE) and the single region FLC (17 % higher ISE) gives a better performance than the ZN-PI controller.

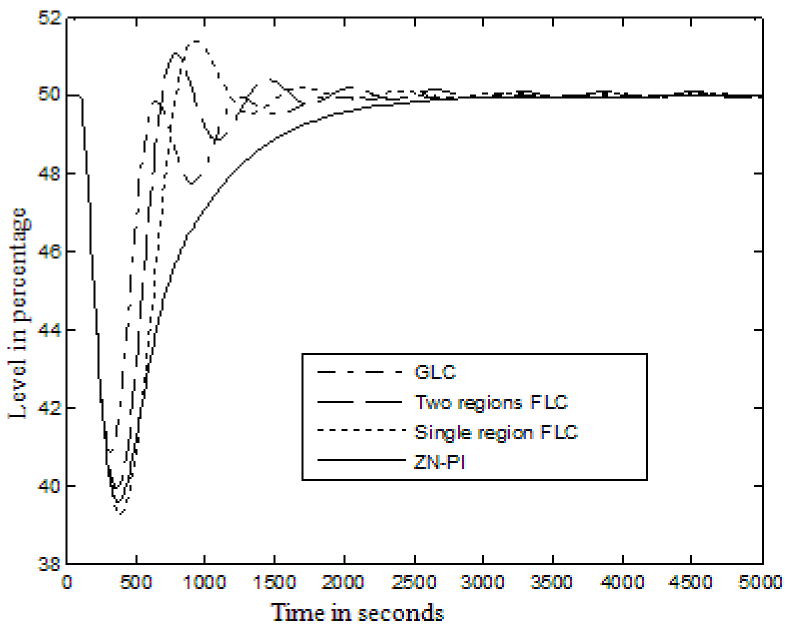

Fig. 5. Regulatory responses for a 15% decrease in load at 50% nominal operating point.

Regulatory responses for a 15 % increase in load at nominal operating point 35 % (refer to Fig. 6) show that the GLC provides a better performance (52 % lesser ISE) than the two region FLC (40 % lesser ISE), single region fuzzy controller (32 % lesser ISE) and ZN-PI controller.

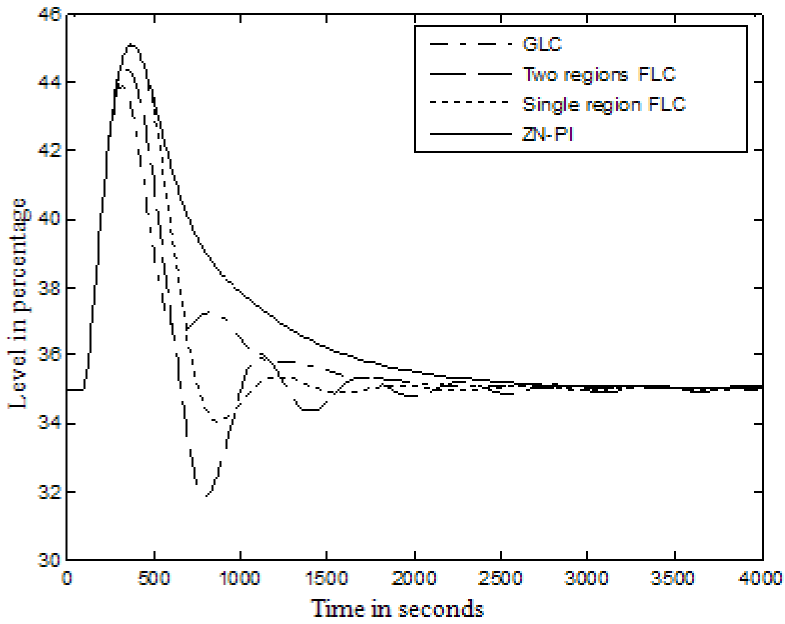

Fig. 6. Regulatory responses for a 15% increase in load at 35% nominal operating point.

Table 3. ISE of Regulatory Responses for 15% decrease in load.

Operating point	ZN-PI	Single Region FLC	Two Region FLC	GLC
50 %	43100	35870	26860	18480
35 %	37820	28150	19680	15470
70 %	48580	44890	33590	21820

Regulatory responses for a 15 % decrease in load at nominal operating point 35 % (refer to Fig. 7) show that the GLC provides a better performance (60 % lesser ISE) while the two region FLC (48 % lesser ISE) and the single region FLC (26 % lesser ISE) also gives a better performance than the ZN-PI controller.

Regulatory responses for a 15 % increase in load at nominal operating point 70 % (refer to Fig. 8) show that the GLC improves the response (53 % lesser ISE) while the ZN-PI gives a poorer performance than the two region FLC (34 % lesser ISE) and single region FLC (10 % lesser ISE).

Servo responses for a 20 % decrease in the set point at nominal operating point 50 % (refer to Fig. 9) show that the GLC gives an improved response (64 % lesser ISE) than the two region fuzzy logic controller (21 % lesser ISE). The single region fuzzy logic controller (11 % lesser ISE) and ZN-PI controller provides a sluggish response.

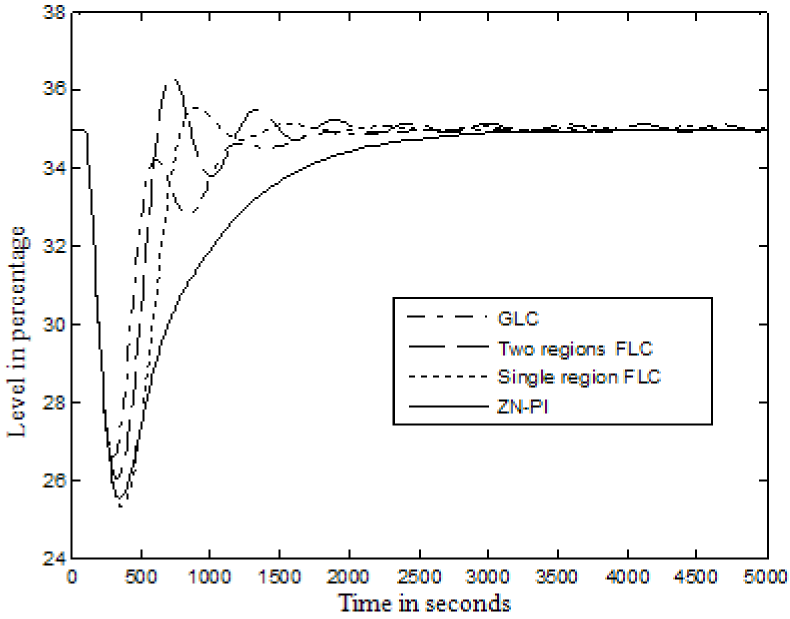

Fig. 7. Regulatory responses for a 15 % decrease in load at 35% nominal operating point.

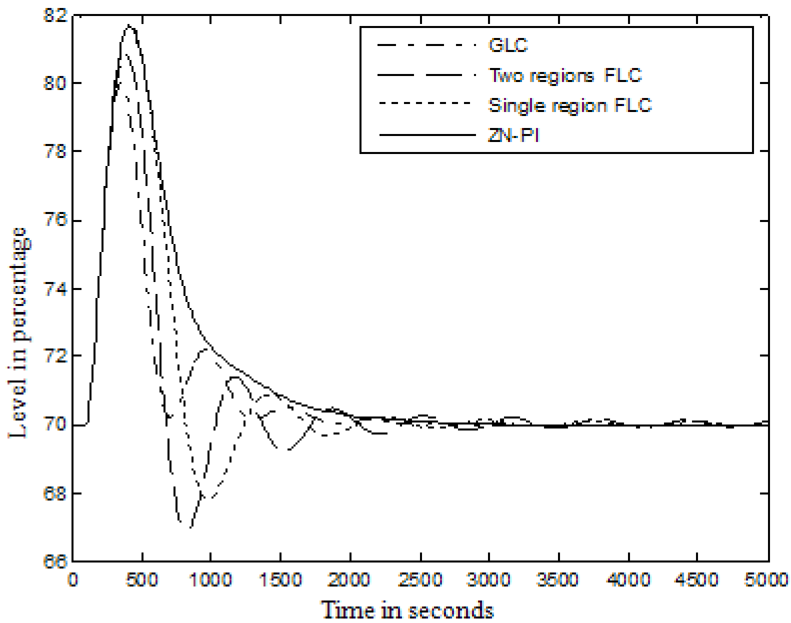

Fig. 8. Regulatory responses for a 15 % increase in load at 70 % nominal operating point.

Table 4. ISE of Servo Responses for 20% decrease in set point.

Operating point	ZN-PI	Single Region FLC	Two Region FLC	GLC
50 %	187900	168200	148900	69450
35 %	227200	177900	150600	71680
70 %	182700	162600	149600	73090

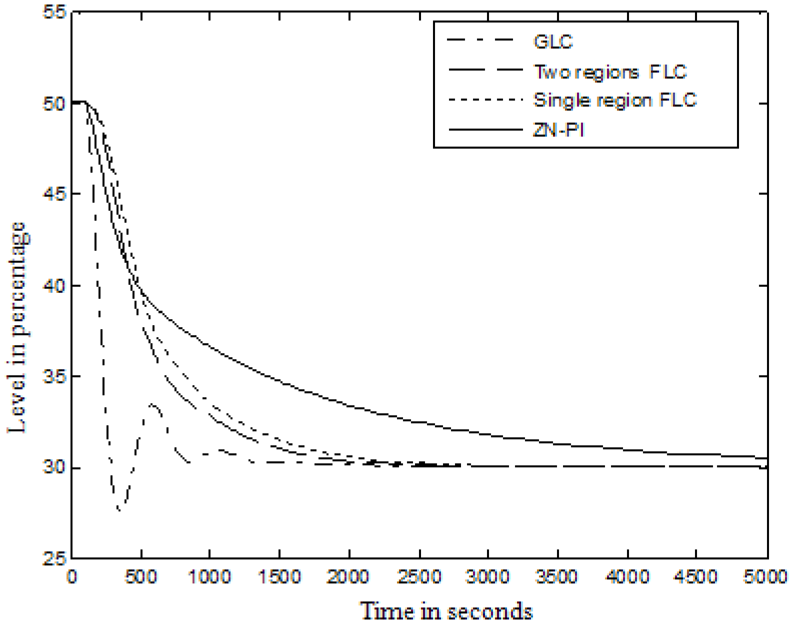

Fig. 9. Servo responses for a 20 % decrease in set point at 50 % nominal operating point.

6. Experimental Work

The SIMULINK blocks are interfaced with the experimental setup through dSPACE [8]. Fig. 10 shows the experimental servo responses for a 10 % decrease in set point at nominal operating point 50 % show that the GLC controller improves the response (16 % lesser ISE) while the ZN-PI controller gives a poorer performance than the two region fuzzy logic controller (11 % lesser ISE) and single region fuzzy logic controller (6 % lesser ISE). Fig. 11 shows the experimental regulatory responses for a 10 % increase in load at nominal operating point 35 % show that that the GLC improves the response (19 % lesser ISE) while the ZN-PI controller gives a poorer performance than the two region fuzzy logic controller (14 % lesser ISE) and single region fuzzy logic controller (9 % lesser ISE).

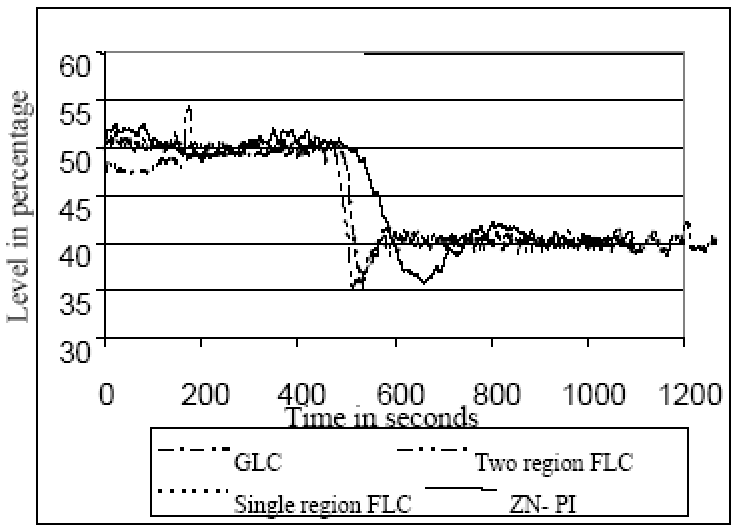

Fig. 10. Experimental Servo responses for a 10 % decrease in set point at 50 % nominal operating point.

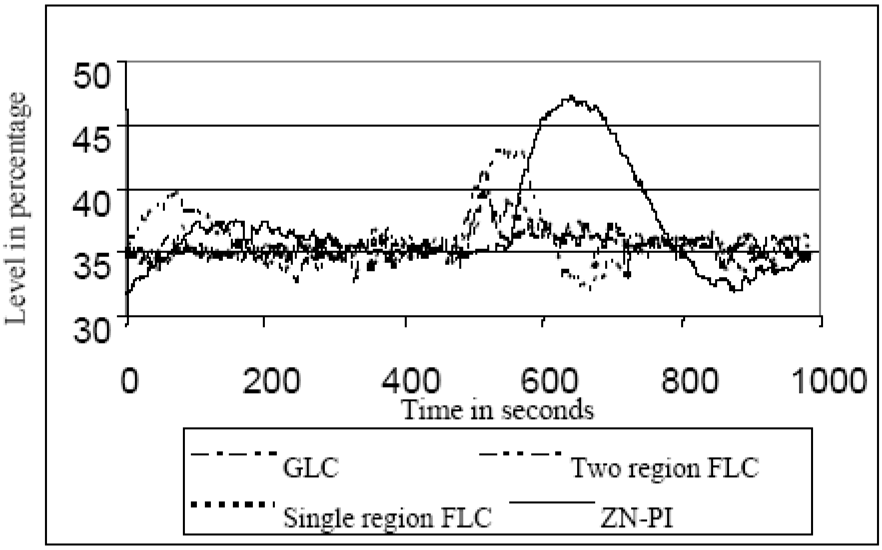

Fig. 11. Experimental Regulatory responses for a 10 % increase in load at 35 % nominal operating point.

7. Conclusion

In this paper a Globally Linearized Controller (GLC), two region, single region fuzzy logic controllers and ZN-PI controller are designed and incorporated on the two capacity interacting nonlinear process. In all cases, the servo and regulatory responses are obtained for different operating points with various set point and load changes through simulation. In order to validate the results obtained through simulation, experimental work is carried out on a two capacity interacting nonlinear process. As found in the simulation analysis, both servo and regulatory responses settles quickly when GLC is employed. Moreover the GLCGLC outperforms the fuzzy controllers even when the operating point of the process is shifted over the entire span.

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Guide for Contributors

Aims and Scope

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