Designing Inverse Fuzzy Model for a Single Tank Liquid Level Control System

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ABSTRACT

A new control strategy for a single tank liquid level control system is designed. Generally PID controllers are used to design the level of the liquid in the tank. But PID is a feedback type controller, so it doesn't produce satisfactory responses. As the complexity of problems in the process increases, Fuzzy Logic Controller is used. It produces satisfactory response, but the drawback is that it is time consuming process and it requires finer tuning and also affected by unknown disturbances. So in order to compensate these kind of unknown disturbances and uncertainties which are seen in the plant, the fuzzy logic controller using inverse fuzzy model is used. The simulation result shows that inverse fuzzy model shows better control action when compared with conventional PID and fuzzy controller. The controllers are designed using MATLAB software.

Keywords
PID Controller, PID Tuning, Fuzzy Logic Controller, Inverse Fuzzy model, Single Tank Liquid System

1. INTRODUCTION

Any real world the systems are nonlinear, time variant, complex and ill defined with unknown plant variations and uncertainties. The good system model is needed for classical control techniques, so that the desired performance can be achieved. But for some kind of intelligent control techniques, such as fuzzy and neural network there is no need of mathematical model. Based on knowledge of the process the fuzzy logic controller rules are framed.

The Single Tank Liquid Level Control System is considered with one inlet and one outlet valve[8]. The aim is to maintain the level of the liquid in the tank. It can be achieved by designing a proper controller. Normally the conventional PID controller [1,4,7] is designed to maintain the level of the liquid in the tank in its set point. But the drawback is, it is feedback type controller that is after the output is affected by error the controller will take control action. And it doesn't accept the sudden change in the set point and the transient behavior of the system is oscillatory.

There are several tuning methods for PID such as Ziegler-Nicholas(I), Ziegler Nicholas(II), Cohen Coon Method, Bode integrals, Disturbance rejection magnitude optimum, Pole Placement and Optimization methods. In this paper Ziegler-Nicholas(I) tuning method [1,4,7] is used. It is an open loop method. From this method we find the values of slope, dead time, steady state gain and time constant. By using these values and substituting it in the formula, the proportional, integral and derivative values for the controller are obtained. By using these as the controller values, the level of the liquid in the tank can be controlled. As the complexity of the problems in the process increases, fuzzy logic controller is used. In most cases, the basic process of the system is not completely known priori. The Fuzzy Logic controller[1,4,5,7] is mainly used in order to minimize the control actions of human operator. Fuzzy control is a control method based on fuzzy logic. In simple, Fuzzy logic can be described as "computing with words rather than numbers" & fuzzy logic control can be described simply as "control with sentences rather than equations".

Fuzzy logic controller[5,7] consists of three parts, such as fuzzification, inference engine and defuzzification. Normally from the plant, the measured variable is in numerical form. So the process of converting the numerical variables to linguistic variables is called as fuzzification. In inference engine IF-THEN rule is framed. Then the linguistic variable is converted into numerical values, so that it can be given to the plant which is called as defuzzification.

The basic methods for fuzzification are sugeno and Mamdani. In inference engine IF-THEN rule is created, and some defuzzification methods are middle of maximum, mean of maxima, first of maximum, center of gravity, center of sums, fuzzy clustering defuzzification method, and adaptive integration.

Fuzzy logic controller[2,9] using inverse fuzzy model can compensate the unknown disturbances and uncertainties that are present in the system. Inverse fuzzy model possess the advantage of open loop method, so it provides inherent stability and perfect control with zero error.

2. SINGLE TANK SYSTEM MODELLINNG

The single tank liquid level [8] control system has one inlet and one outlet. The aim is to maintain the level of the liquid in the tank. Let Qin be the liquid flow rate into the tank, Qout be the outlet flow rate from the tank, h be the variable height of the liquid in the tank and H be the constant height. It is known that the output flow rate varies as the square root of the height, Qout=K*sqrt(h) , so if the level is high, then faster the liquid flows out. If the output flow rate is not exactly equal to the input flow rate, the level will drop, (Qout > Qin) or rise,if (Qout < Qin). Generally valve is the final control element seen in the level process station. The control variable is the variable which is need to be maintained(level).

The physical equation[8] governing the change in liquid volume is: rate of change in the volume of liquid = inflow – outflow

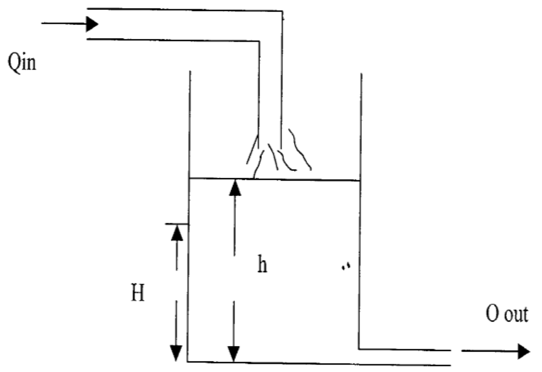


Fig 1. Single Tank System

Thus, if the inflow was equal to the outflow, then no change in the volume of liquid which is seen in the tank. We have, using the above physical principle:

$$A\frac{dh(t)}{dt} = qi - qo \qquad \ldots\ldots (2.1)$$

We will assume

1. a constant cross-sectional area for the tank (*A*)

2. the outflow is proportional to the height of liquid:

$q_{out}=h(t)/R$ where *R* represents a parameter due to pipe restrictance.

$$A\frac{dh(t)}{dt} = qi(t) - qo(t) \qquad \ldots\ldots\ldots (2.3)$$

Substitute equation (2.2) in equation (2.3), we get as

$$AR\frac{dh(t)}{dt} = qi(t) - h(t \qquad \ldots\ldots\ldots(2.4)$$

$$AR\frac{dh(t)}{dt} + h(t) = R\, qi(t) \qquad \ldots\ldots\ldots(2.5)$$

We have an equation with one first-order derivative, $\frac{dh(t)}{dt}$

So it is a first order system.

Taking Laplace transform for the above equation (2.5), we get

$$AsH(s)+H(s) = RQi(s) \qquad \ldots\ldots \quad (2.6)$$

$$H(s)[As+1] = RQi(s) \qquad \ldots\ldots \quad (2.7)$$

$$\frac{H(s)}{Qi(s)} = R/(A_oS+1)$$

Letting $AR = \tau$ and $K = R$, then the above equation (2.8) will becomes:

$$G(s) = K/(\tau q\, s+1)$$

Where K - gain of the system
τq – time constant
R – flow resistance
A – Tank cross sectional area
Qin – inflow rate into the tank
Qout – outflow rate from the tank
H - constant height
h - variable height

3. DESIGNING SYSTEM WITH PID CONTROLLER

The PID controllers[1,4,7] are the most commonly used controllers in industries. There are several methods for tuning the PID controllers such as Ziegler Nicholas, Cohen Coon method, disturbance rejection etc. In this paper, Ziegler Nicholas(I) tuning method is used.

Ziegler-Nicholas(I) tuning method [1,4] is an open loop method. From this method, the S shaped curve is obtained. From this curve, find the values for slope, dead time, steady state gain and time constant. By using these values and substituting it in the formula, the proportional, integral and derivative values for the controller is obtained

Normally PID controller is a kind of feedback type controller. So, the controller will take the corrective action after the output is affected by error. It was a major disadvantage of PID controller. The practical disadvantage of PID controller is fixing gain values to the controller. The simulated response shows the presence of overshoot. The transient behavior of the system will be oscillatory.

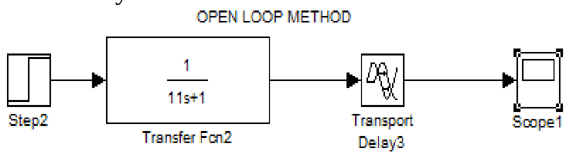


Fig 2. MATLAB/Simulink model for open loop method

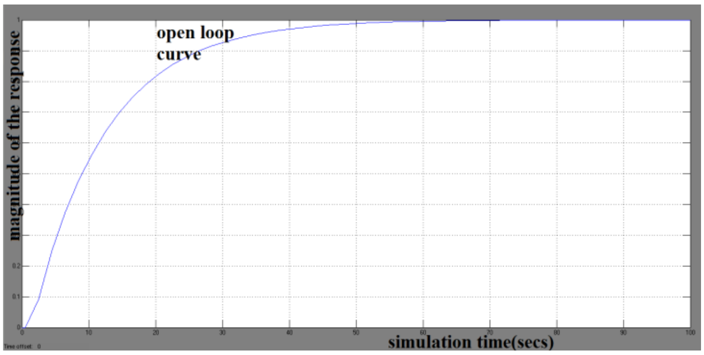


Fig 3. Response of system in open loop method

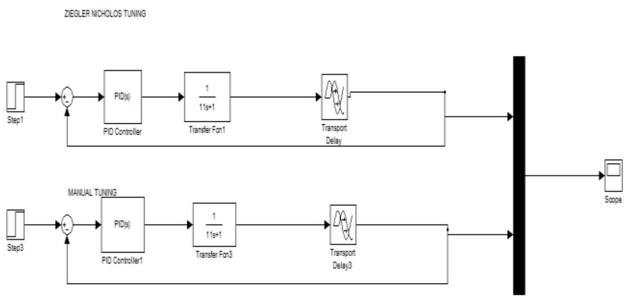


Fig 4. MATLAB/Simulink model for PID controller

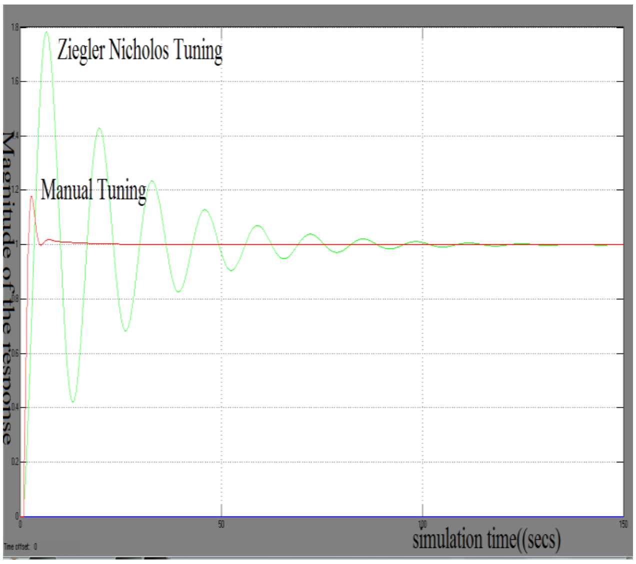


Fig 5. Response of the system using PID controller

The response of the system in Ziegler Nicholas tuning has many oscillations and overshoot is seen. So, in order to reduce the oscillations and overshoot, manual tuning is done.

4. DESIGNING SYSTEM WITH FUZZY LOGIC CONTROLLER

Fuzzy logic controller[1,4,5,7] can be used for the process which is nonlinear and time varying. It is the controller which can be designed based on the human knowledge. This controller can mimic the control actions of human operator.

Fuzzy logic controller consists of three parts[5,7], such as fuzzification, inference engine and defuzzification. Normally from the plant, the measured variable is in numerical form. So the process of converting the numerical variables to linguistic variables is called as fuzzification. In inference engine IF-THEN rule is framed. Then the linguistic variable is converted into numerical values, so that it can be given to the plant which is called as defuzzification.

The basic methods for fuzzification are sugeno and Mamdani. In inference engine IF-THEN[1,4,7] rule is created, and some defuzzification methods are middle of maximum, quality method, mean of maxima, center of sums, center of the largest area semi linear defuzzification, last of maximum, center of gravity, fuzzy clustering defuzzification, and adaptive integration. The proposed fuzzy controller is a two-input one-output system: the error e(t) and the change in error ce(t) are the controller inputs while the output is y(t).

The membership function which we are considering is triangular membership function[5] for both input and output. Labels has been assigned to each membership function such as high negative(HN), low Negative(LN), zero error(ZE), high positive(HP) and low positive(LP) for the input of the fuzzy Controller.

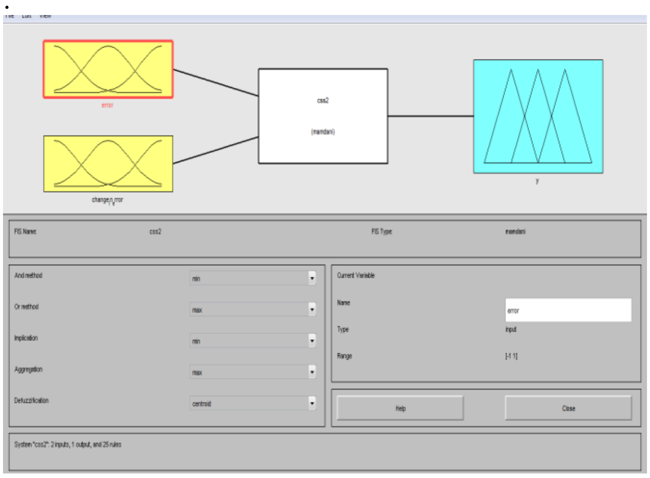


Fig 6. Fuzzy Logic controller

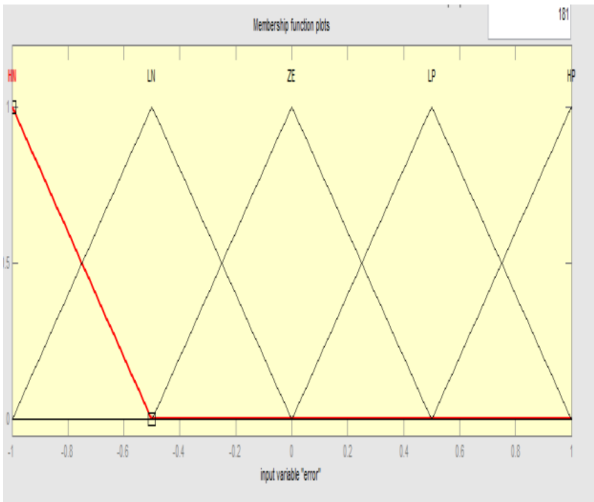


Fig 7. Membership function for input1 and input2 signal

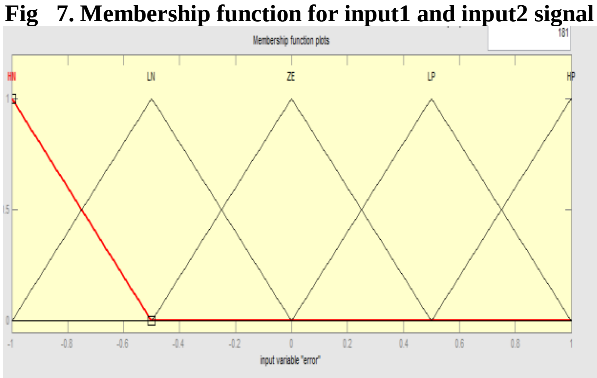


Fig 8. Membership function for output signal

TABLE 1.
FUZZY RULES FOR DEVELOPING FIS FOR FUZZY LOGIC CONTROLLER

CE \ E	HP	LP	ZE	LN	HN
HP	HN	HN	HN	LN	ZE
LP	HN	HN	LN	LN	LP
ZE	HN	LN	ZE	ZE	HP
LN	LN	ZE	LP	HP	HP
HN	LP	ZE	HP	HP	HP

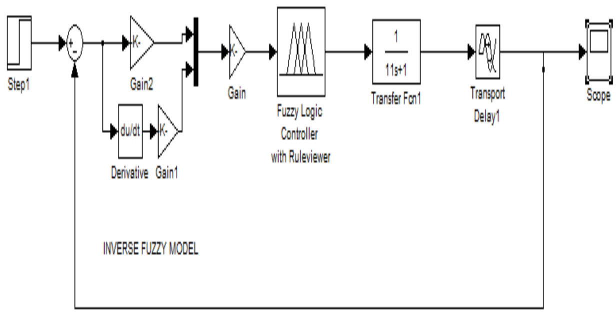


Fig 9. MATLAB/Simulink for Fuzzy Logic Controller

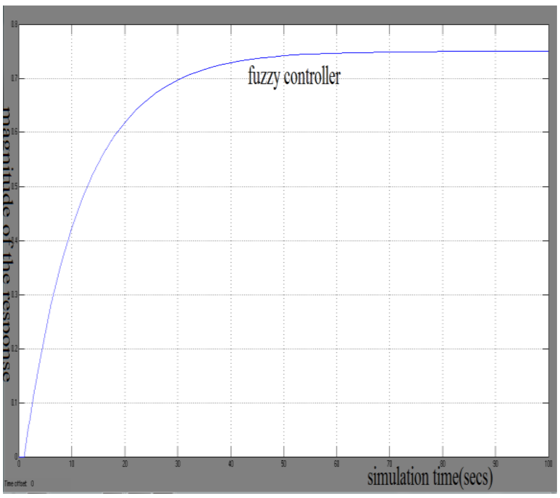


Fig 10. Response of the system using Fuzzy Logic Controller

The response of system using Fuzzy Logic Controller is smooth and oscillations and overshoots ere not seen.

5. DESIGNING SYSTEM WITH FUZZY LOGI CONTROLLER USING INVERSE FUZZY MODEL.

Generally most of the system seen in industries are nonlinear, time invariant and affected by external disturbances. The inverse fuzzy model [2,9] is constructed for a system in order to eliminate the unknown plant variations and disturbances.

In theory, the use of an inverse model possesses the advantages of open-loop control, i.e. inherent stability and perfect control with zero error.

The inverse fuzzy model for the system can be obtained by means of different linguistic inversion techniques[3]. They are partial and global .

Global Inversion[3] is a kind of linguistic inversion seen in the system, where all states become the outputs of the inverted model and the output of the original system becomes the input .

Partial Inversion[3] is a kind of linguistic inversion in which only one of the states of the original system becomes the output of the inverted model and other states along with the original output are the inputs for the Fuzzy Logic Controller using the inverted model[2,9].

The proposed fuzzy controller using inverse fuzzy model is a one-input one-output system: the output is y(t) is given as the input to the fuzzy controller and the input error e(t) will be the output of the fuzzy controller.

The membership function which we are considering is triangular membership function for both input and output. Labels has been assigned to each membership function such as high negative(HN), low Negative(LN), zero error(ZE), high positive(HP) and low positive(LP) for the input of the fuzzy controller

6. STEPS TO DEVELOP THE INVERSE FUZZY MODEL

There are three steps to develop the inverse fuzzy model for the system[2,9]. They are:-

Step1:

The starting point of the proposed Inverse Fuzzy modeling approach is to defined and construct a fuzzy partition of the universe of discourse of each component of the control input vector.

Step2:

A fuzzy partition is realized by associating by membership function to each interval.

Step 3:

Finally in this step the fuzzy rules are defined.

Fig 11. Fuzzy Logic Controller using Inverse Fuzzy Model

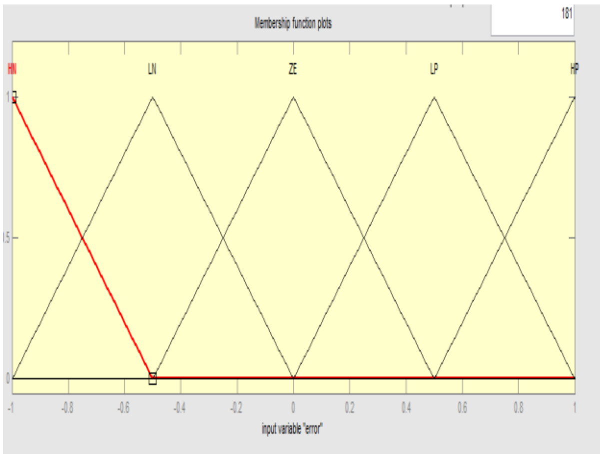


Fig **12.Membership Function for input and output signal**

7. CONSTRUCTING FUZZY RULES FOR INVERSE FUZZY MODEL

In general fuzzy rules is constructed as ,

IF x is Fa , THEN y is Fb

Where x and y are the inputs and the output of the system.

Incase of inverse fuzzy model , the fuzzy rules[2,9, 10, 11, 12] is in the following form:

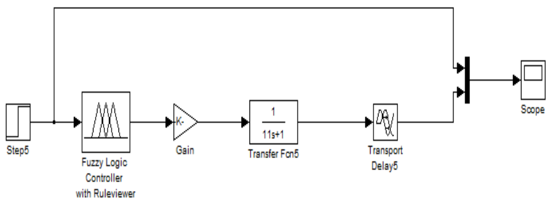
IF y is Fk , THEN x is Fj

.Where y – output and x - input of the system. The no of rules in fuzzy logic controller is more than the rules which is used in fuzzy inverse model. Less no of rules give better result. Because some of the fuzzy rules are not invertible. Here we use 25 fuzzy rules to construct the fuzzy model. But here only 5 rules are used for inverse fuzzy model.

The rules are in the form,

1. IF Y is HN THEN e is LN.
2. IF Y is LN THEN e is HN.
3. IF Y is ZE THEN e is ZE.
4. IF Y is LP THEN e is HP
5. IF Y is HP THEN e is LP.

Fig 13. MATLAB/Simulink model for fuzzy logic controller using inverse fuzzy model



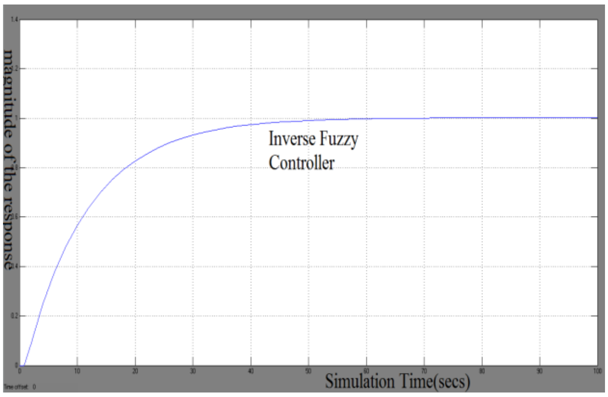


Fig 14. Response of the system using inverse fuzzy Model.

The response of the system obtained using inverse fuzzy model can eliminate the error to zero. So the level control action is achieved in a perfect manner by using the inverse fuzzy model

8. COMPARING THE RESPONSE OF THE SYSTEM USING DIFFERENT CONTROLLERS

There are three different controllers used to control the level of the liquid in the tank. They are Conventional PID, Fuzzy Logic Controller and Fuzzy Logic Controller using inverse fuzzy model.

The response of the controller is compared based on certain performance criterion such as Rise time (secs), Settling time (secs), transient behavior, Steady state error(Ess), Maximum peak overshoot(Mp in%).

From the simulation response of different controllers these parameters are measured and the response of fuzzy logic controller using inverse fuzzy model has better control action then compared with fuzzy logic controller and conventional PID.

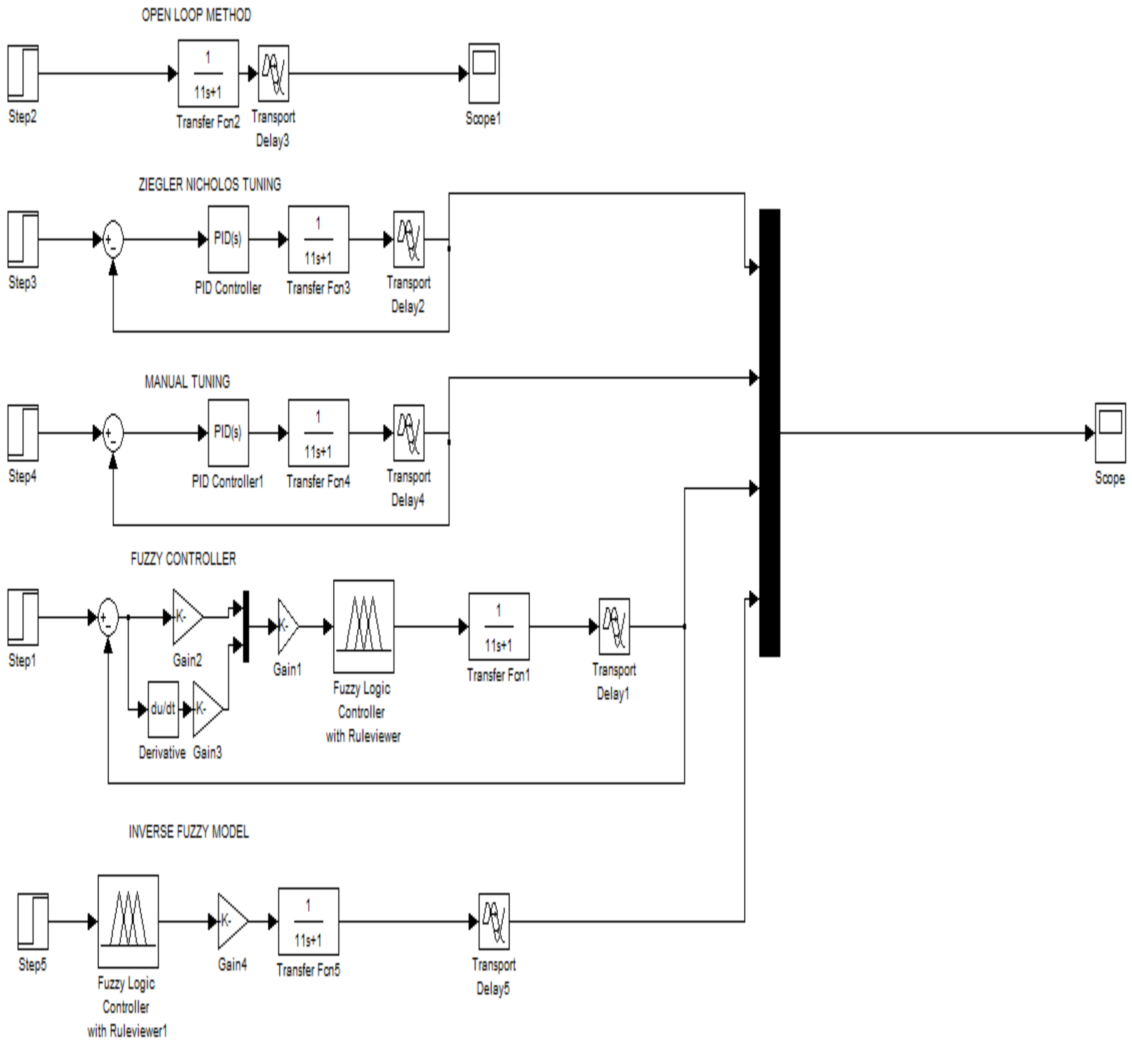


Fig 15. MATLAB/Simulink model using different Controllers

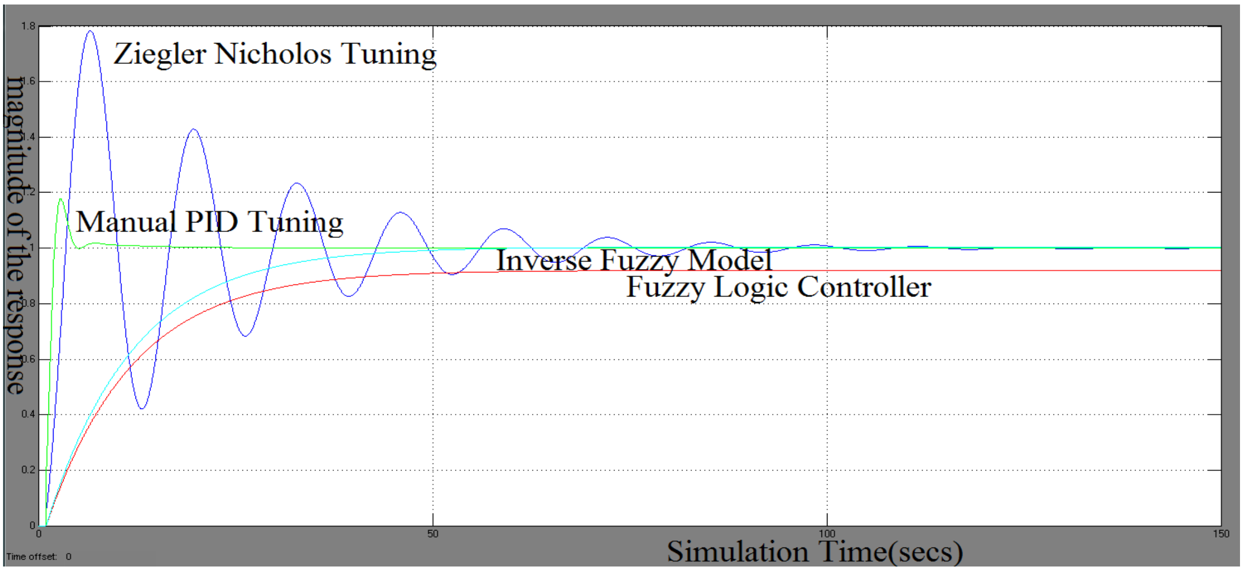


Fig 16. Response of the system using different controllers

TABLE II
PERFORMANCE EVALUATION OF DIFFERENT CONTROLLERS

Si no	Controller	Tr (secs)	Ts (secs)	Mp (%)	Transient Behavior	Ess
1.	ZN-I Tuning	2.1	120	7.9	Oscillatory	0
2.	Manual PID Tuning	3.5	30	1.9	Oscillatory	0
3.	Fuzzy Logic Controller	35	70	NO	Smooth	5.8
4.	Inverse Fuzzy Model	40	55	NO	Smooth	0

9. CONCLUSION

Hence, in this paper initially, the Conventional PID Controller is used as level process controller in tank. Then Fuzzy Logic based intelligent controller is introduced. Later on, the Fuzzy Logic Controller using Inverse Fuzzy Model was introduced. The performance is evaluated against each other and from Table 2, the following parameters such as rise time, peak overshoot, settling time etc can be observed. Even though, the PID Controller produces the response with low rise time, it has severe oscillations with a very high peak overshoot of 7.95%. This causes the damage in the system performance. To suppress these severe oscillations that are seen in the system, Fuzzy Logic Controller is proposed to use. The result shows that, the fuzzy logic controller which can effectively suppress the oscillations and produce smooth response. But the fuzzy logic controller gives a steady state error of 5.8%. Furthermore, to suppress the steady state error, it is proposed to use Inverse Fuzzy Model. The results shows that, this design can effectively suppress the error (i.e) there is no error.

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