iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 Issue: X Month of publication: October 2017

DOI: http://doi.org/10.22214/ijraset.2017.10294

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue X, October 2017- Available at www.ijraset.com

Max Min Composition Based Multilevel PID Selector with Reduced Rules and Complexity in FIS for Servo Applications

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Abstract: In PID the controller parameters are fixed which compromises the required system control. This work presents the updation of controller parameters by an Intelligent PID selection using Max Min composition for Servo applications. The controller parameters are obtained by using well known tuning techniques namely Ziegler Nichols and Modified Ziegler Nichols. The simulation work carried out depicts improved performance of Servo plant for 3 level and 5 level Intelligent PID compared to Fuzzy logic controller with respect to steady state and transient behavior. It is also observed that the system performs well to the introduction of disturbance into the plant. The performance analysis is conducted by using MATLAB.
Key Words: PID controller, Ziegler Nichols tuning, Modified Ziegler Nichols tuning, Fuzzy Logic Controller.

I. INTRODUCTION

The industrial applications of servomotors include robot manipulators, automotive and aircraft which require superior controllers where control of position, speed and acceleration is the requirement [1][2][3]. PID controller is one such controller which is seen in almost 90% of the industries due to its accessibility and practicality. The conventional PID controller is used for the analysis of system transient response and steady state response [4]. It requires precise and effective tuning of parameters to meet the closed loop system performance [5]**.**This search has initiated for evolution of intelligent controllers which framed the tuning and design to ease [4].The background of fuzzy logic enables required intelligence and its advantages include – no requirement of mathematical models, it has a flexibility of adjustments and large number of inputs, human experience can be applied [6].

A fuzzy logic controller is a rule based system. Even though this system has notable applications for motor drive for varying system parameters, it also has the complication of defining rules and shape of membership functions in order to analyze the system behavior [6].

This paper has following contributions. Firstly, design of Ziegler Nichols tuned PID controller. Secondly the best PID by Modified Ziegler Nichols tuning is obtained. Thirdly the design of fuzzy logic controller is done. An Intelligent PID selector using Max min composition with 3 level and 5 level is being proposed. The Max min composition is used to give the relation between fuzzy sets. This approach is having benefits compared to Fuzzy Inference system.1) The membership functions are eliminated which are used to give degree of value. 2) The number of rules has been reduced in analysis of the system thus reducing the complexity. 3) No requirement of Defuzzification, for a Madmani inference the output can is obtained by centroid method.

II. DESIGN OF INTELLIGENT PID SELECTION BY MAX MIN COMPOSITION

A. *Step 1*: The input used is Step signal and the error which is the difference between output and input is utilized for the analysis of the system in an Intelligent N level PID controller
B. *Step 2:* For an Intelligent N level PID controller, each controller parameter is obtained from the Modified Ziegler Nichols tuning technique and these are considered as the best parameters (P_B, I_B and D_B).
C. *Step 3*: In this analysis, each controller gain block is allocated with N number of gain blocks
D. *Step 4:*Now let us consider modulus of error |e| and modulus of rate of change of error$|\dot{e}|$ to be inputs of Max block as shown in fig 1 and this Max operator gives the maximum of the inputs |e| and $|\dot{e}|$.
E. *Step 5:* The output obtained at the Max block is normalized and it is given to the error selection block refer fig1 and for an Intelligent N level PID controller, the error selection is made into regions as $0, \frac{1}{N}, \frac{2}{N}, \dots, \frac{N-1}{N}$
F. *Step 6:* The selection of gain from a N level gain selection block is made based on the comparison of normalized output with segmented N level regions and this information is utilized for giving control input to the multiport switch.

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*G. Step 7:*The mathematical expressions for gains is given as Proportional gain by $(1-\frac{1}{5n})P_B$, P_B ,$(1+\frac{n+1}{2})P_B$,where n=1,2,3

H. Step 8: The expression for Derivative gain is given by $(1-\frac{1}{n+2})$ D_B , D_B , $(1+\frac{1}{n+2})$ D_B , where n=1,2,3

I. Step 9: The expression for Integral gain is given by $(1+\frac{1}{n+2})$ I_B , I_B , $(1-\frac{1}{n+2})$ I_B , where n=1,2,3

J. Step 10: Thus the gain values obtained are fed to plant for monitoring the control of servo system and thus maintaining the deviation to minimum.

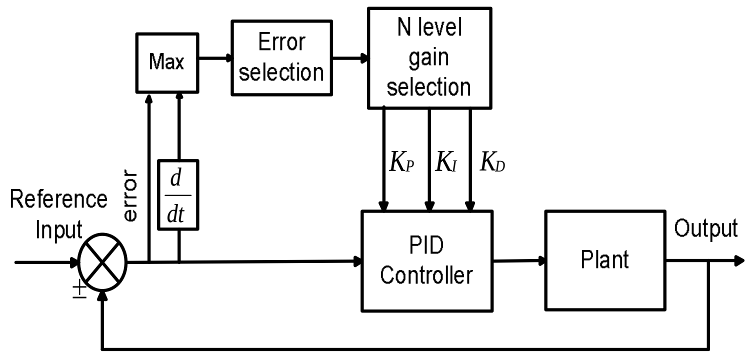

Figure1. Block diagram of Intelligent PID selector by Max Min composition

K. Application of Intelligent 3 level PID gain selector

From Step 5 and N= 3, the regions partitioned are given by 0, $\frac{1}{3}, \frac{2}{3}$ and From the Steps 8&9, respective derivative and integral gains can be obtained by putting n=3 and proportional gain can be obtained by keeping n=1 in Step 7 and it is tabulated as shown below.
The rules for the selection of forward gain to be added for proportional gain is

Rule 1: f Max (e,-e,$\dot{e}, -\dot{e}$) is > 2/3 then select gain value as $(1+\frac{2}{2})$ P_B

Rule 2: If Max (e,-e,$\dot{e}, -\dot{e}$) is > 1/3 then select gain value as P_B

Rule 3: If Max (e,-e,$\dot{e}, -\dot{e}$) is > 0 then select gain value as$(1-\frac{1}{5})$ P_B

Similarly the integral and derivative gain rules can be written as shown in the Table I

TABLE I: INTELLIGENT 3 LEVEL PID GAIN SELECTOR

	Controller		
Gain	P	I	D
	$(1-\frac{1}{5})$ P_B	$(1+\frac{1}{5})$ I_B	$(1-\frac{1}{5})D_B$
	P_B	I_B	D_B
	$(1+\frac{2}{2})P_B$	$(1-\frac{1}{5})I_B$	$(1+\frac{1}{5})D_B$

L. Application of Intelligent 5 level PID gain selector

From the Step 5, N= 5 the regions partitioned are given by 0, $\frac{1}{5}, \frac{2}{5}, \frac{3}{5}, \frac{4}{5}$ and From Steps 8&9 the respective derivative and integral gains can be obtained for n=2,3 and from Step 7proportional gain can be obtained for n=1,2 it is tabulated as shown below.
The rules for proportional gain is

Rule 1: If Max (e,-e,$\dot{e}, -\dot{e}$) is > 4/5 then select gain value as$(1+\frac{3}{2})P_B$

Rule 2: If Max (e,-e,$\dot{e}, -\dot{e}$) is > 3/5 then select gain value as $(1+\frac{2}{2})P_B$

Rule 3: If Max (e,-e,$\dot{e}, -\dot{e}$) is > 2/5 then select gain value as P_B

Rule 4: If Max (e,-e,$\dot{e}, -\dot{e}$) is > 1/5 then select gain value as $(1-\frac{1}{5})$ P_B

Rule 5: If Max (e,-e,$\dot{e}, -\dot{e}$) is> 0 then select gain value as$(1-\frac{1}{10})$ P_B

Similarlythe integral and derivative gain rules are given below in Table II

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Table II: Intelligent 5 Level Pid Gain Selector

Controller			
Gain	P	I	D
	$(1-\frac{1}{10})$ P_B	$(1+\frac{1}{4})$ I_B	$(1-\frac{1}{4})D_B$
	$(1-\frac{1}{5})$ P_B	$(1+\frac{1}{5})$ I_B	$(1-\frac{1}{5})D_B$
	P_B	I_B	D_B
	$(1+\frac{2}{2})P_B$	$(1-\frac{1}{5})$ I_B	$(1+\frac{1}{5})D_B$
	$(1+\frac{3}{2})P_B$	$(1-\frac{1}{4})$ I_B	$(1+\frac{1}{4})D_B$

III. IMPLEMENTATION ON SERVOMOTORS

The requirement of position control is facilitated by DC Servo motors which are nothing but DC motors. They are more suitable for high-performance system because it has the high starting torque to inertia ratio and fast dynamic response [3].

A. Modelling of a dc servo motor

The air gap flux is proportional to the field current [6]

$\Phi = K_f\, i_f$ ………….. (3)

The torque is given a

$T = K_1\, K_f\, i_f$ ……………(4)

K_1 is constant.

Let us keep field current as constant, then T_M is given as

$T_M = K_T\, i_a$ ………….. (5)

K_T is motor torque constant,

The motor back emf is proportional to speed,

$e_b = K_b\frac{d\theta}{dt}$ …………… (6)

where e_b back emf constant.

The armature circuit differential equation is

$e = L_a\frac{dia}{dt} + R_a\, i_a + e_b$ ……………. (7)

The torque equation is

$T_M = K_T\, i_a = J\frac{d^2\theta}{dt^2} + f\frac{d\theta}{dt}$ …………… (8)

by Laplace transforms we get,

$E_b(s) = K_b s\, \theta(s)$ ……………… (9)

$I_a(s)\, (L_a s + R_a) = E(s) - E_b(s)$

$\theta(s)\, (Js^2 + f_0 s) = K_T\, I_a(s)$ ………….. (10)

The transfer function can be obtained as

$\frac{\theta(s)}{E(s)} = \frac{K_T}{s((L_a s+R_a)(Js+f_0)+K_T K_b)}$………..(11)

TABLE III: PARAMETERS OF SERVOMOTOR [6]

Parameters	Values
Moment of Inertia (J)	42.6×10^{-6} Kg-m^2
Friction Coefficient(f_0)	47.3×10^{-6} Nm/rad/s
Back EMF constant (K_b)	15×10^{-3} V/rad/s
Torque constant(K_T)	15×10^{-3} N-m/A
Resistance(R_a)	2 Ohms
Inductance(L_a)	1 mH

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IV. PID TUNING TECHNIQUES

From the literature [7] there are following tuning techniques.

In this work, in order to obtain the PID controller parameters Ziegler Nichols and Modified Ziegler Nichols tuning techniques are used.

A. Ziegler Nichols tuning method

It is a practical approach of tuning the PID controller [8]. The approach used here is the Ziegler Nichols closed loop tuning which has the following steps have been presented below [6].

Step 1: Initiate the procedure by keeping Integrative gain and derivative gain to zero

Step 2: Then gradually increase the proportional gain until the system response tends to instability

Step 3: There seen a continuous oscillation in the response at gain called K_u, which is used for the determination of period P_u.

Step 4: These values are required for calculating the PID controller parameters by using the tabular form given by the Ziegler and Nichols.

Table IV: Pid Controller Parameters For Ziegler Nichols Method [6]

Controller Parameters	K_P	T_I	T_D
PID	$K_u/1.7$	$P_u/2$	$P_u/8$

Application of Ziegler Nichols tuning for Servo system

Mathematical illustration of Ziegler Nichols tuning for obtaining gain and frequency

$$G(s) = \frac{0.015K}{4.2x10^{-8}s^3+8.5x10^{-5}s^2+3.1x10^{-4}s}$$

Considering characteristic equation we get

$$4.2x10^{-8}s^3 + 8.5x10^{-5}s^2 + 3.1x10^{-4}s + 0.015K = 0$$

From Routh Hurwitz criteria, the range of K for stability for servo system transfer function is

$0 < K < 41.8$

This implies for K= 41.8 the sustained oscillations occur at ω = 85.9 rad/sec frequency

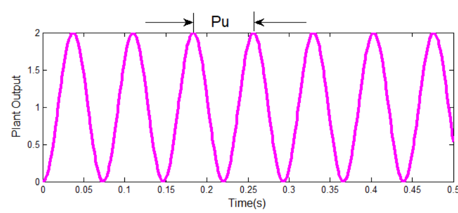

Figure 2. Response of the system

Hence the values for Ku = 41.8, Pu = $2\pi/85.9$=0.073 and this information is used for calculating the K_P,K_I and K_D values. It is tabulated and presented as shown below

Table V: Pid Parameters Of Servomotor Using Zn Tuning

Controller parameters	K_P	T_I	T_D
PID	24.58	0.037	0.009

B. Modified Ziegler Nichols tuning

PID control is used to move a point A on the nyquist plot of an unregulated system to an arbitrary point A_1 on the regulated system such that the desired phase margin and gain cross over frequency is obtained [7][9].

The complex gain for point A is $G(j\omega_0)=r_a e^{j(\pi+\emptyset_a)}$ and A_1 is $G(j\omega_0) = r_b e^{j(\pi+\emptyset_b)}$ and PID controller frequency ω_0 is $G_c(s) = r_c e^{j\emptyset_c}$

$e^{j(\pi+\emptyset_b)} = r_a r_c e^{j(\pi+\emptyset_a+\emptyset_c)}$ …………(11)

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$r_c = \frac{r_b}{r_a}$ and $\emptyset_c = \emptyset_b - \emptyset_a$

From the above analysis the tuning values for the design of PID can be given as below

$K_P = \frac{r_b \cos(\emptyset_b - \emptyset_a)}{r_a}$ …………..(12)

$T_I = \frac{1}{2\alpha\omega_0}(\tan(\emptyset_b - \emptyset_a)\sqrt{4\alpha + \tan^2(\emptyset_b - \emptyset_a)}$ ………..(13)

$T_D = \alpha T_i$ …………….(14)

From the above equation (11) & (12) K_I can be calculated as $K_I = \frac{K_P}{T_I}$ and K_D is calculated as $K_D = K_P\, T_D$

Application of Modified Ziegler Nichols tuning for a servo system.

Fig.3 denotes the response of the system at which r_b= 0.4, pb is varied from 30^0 to 70^0 and $\emptyset_a = 0$. From which at pb = 50^0 system response was seen better and the values for T_I and T_D are been calculated from eqn (13)&(14). For our convenience pb is used as notation instead of $\emptyset_b$ in MATLAB.

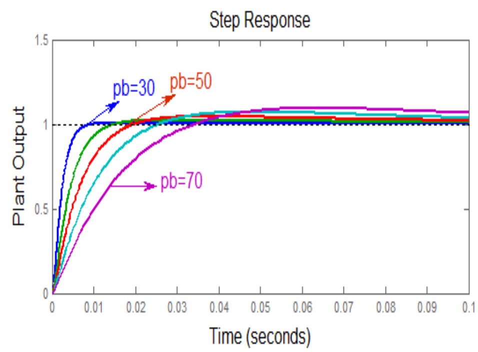

Figure3. System response for different pb

Fig.4 shown below denotes the response of the system with pb is fixed to 50^0,$\emptyset_a = 0$ and r_b is varied from 0.1 to 0.6 and for rb = 0.4 K_P is calculated from the eqn(12).

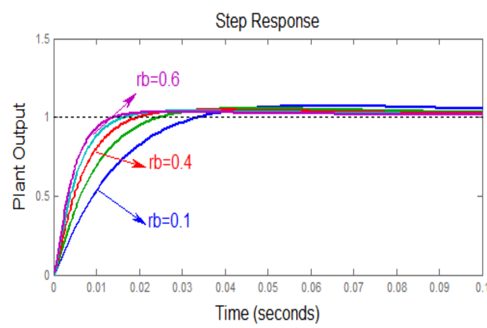

Figure 4. System response for different r_b

Table VI: Pid Parameters Of Servomotor Using Zn Tuning

Controller parameters	K_P	T_I	T_D
PID	24.58	0.037	0.009

V. DESIGN OF FUZZY LOGIC CONTROLLER

The classical mathematics and conventional control theory are restrained for design and regulation of the complex non-linear dynamic systems. The incentive for using Fuzzy Logic – it is more suitable for controlling a system with varying parameters [10][11].

Fig.5 represents the block diagram of Fuzzy Logic cntroller and it has the following stages Fuzzification, Inference and Defuzzification.

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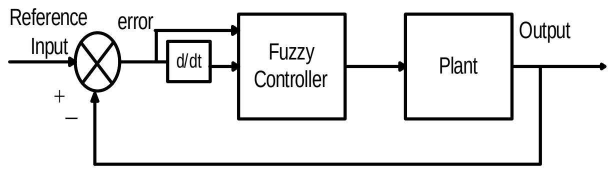

Figure5. Block Fuzzy Logic Controller

A. Algorithm for fuzzy logic controller design:

Step 1: The error and derivative of error is considered as inputs for the fuzzy system

Step 2: The inputs have five membership functions each and the output has seven membership functions which are triangular and trapezoidal. The membership functions are labeled as follows NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PB (positive big), PM (positive medium), PS (positive small).

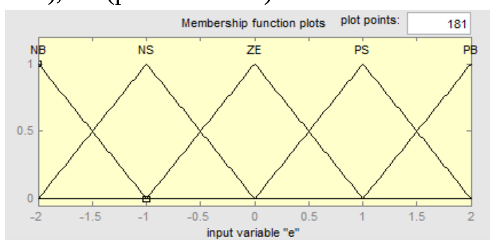

Figure 6. Membership function for input error

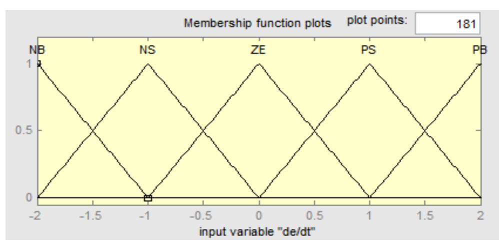

Figure 7. Membership function for input de/dt

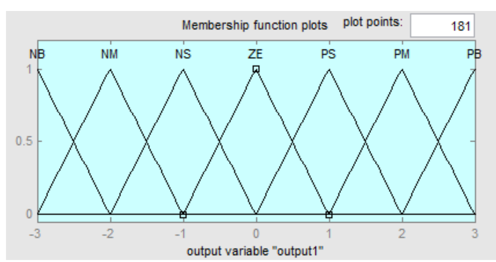

Figure 8. Membership function for output

Step 3: The ranges for the membership function is taken from the best PID error and derivative of error plots.

Step 4: A rule base which directs the control output dependingupn the rules. It can be seen from the Table VII which has rules for 3x3 and Table VIIIhas 5x5 rules for the system analysis.

Table Vii: The 3x3 Rule Base Table Of The Fuzzy Controller[11]

de/dt e	P	ZE	N
P	PB	P	ZE
ZE	P	ZE	N
N	ZE	N	NB

Step 5: Madmani technique is used as defuzzification, output is obtained by centroid.

Table Viii: The 5x5 Rule Base Table Of The Fuzzy Controller[10]

de/dt e	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PB	PB
PB	ZE	PS	PB	PB	PB

VI. RESULTS AND DISCUSSION

In the proposed work, the PID controller parameters obtained are as P_B=10, I_B=2.5 and D_B=0.55 which are approximately equal to Modified Ziegler Nichols tuning values.

Fig.9 depicts the comparison of PID, ZieglerNichols tuned PID and Modified Ziegler Nichols tuned PID. The response simulation time is observed for 2 sec. The proposed PID has better performance as it has better impact on reducing the % overshoot, refer Table

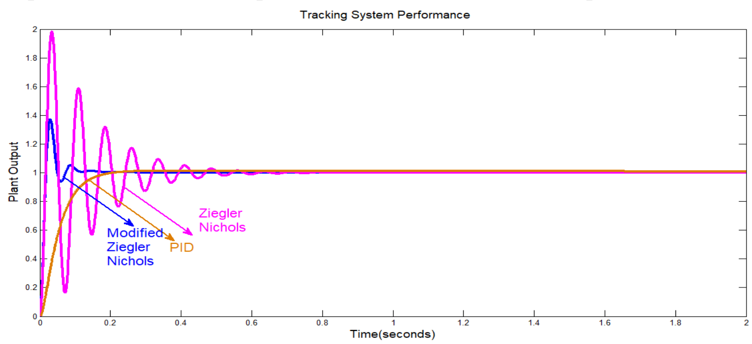

Figure 9. Comparison of ZN tuned PID, Modified ZN tuned PID and Proposed PID

A. *Intelligent 3 level PID gain selector and 5 level PID gain selector:*

Tracking performance of the system with comparison of 3 level and 5 level PID gain selector. The total analysis is conducted for simulation time of 5 sec in which the transient analysis was observed for simulation time of 0-1sec and steady state response was observed for 4-5sec.The Intelligent 5 level PID is seen to meet the desired value to a fast rate than the 3 level.

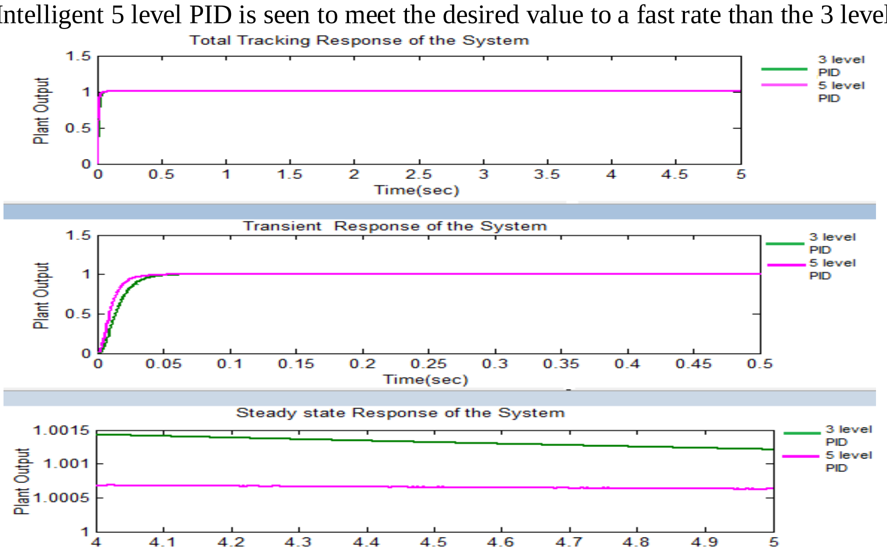

Figure 10.Tracking system performance of Intelligent 3 level and 5 level PID gain selector

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue X, October 2017- Available at www.ijraset.com

B. Intelligent 3 level PID gain selector and 3 level Fuzzy Logic Controller

The tracking response has been observed for the simulation time of 5 sec, the simulation time for transient region is 0-1sec and the simulation time for steady state part is 4-5 sec. From this, Fuzzy logic controller response is deviated from desired value and hence the Intelligent 3 level PID gain selector has good performance.

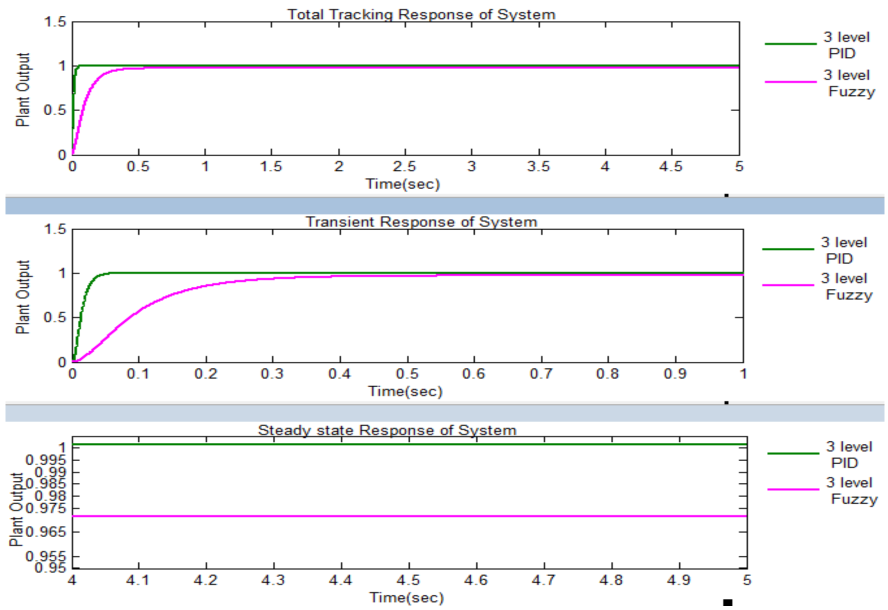

Figure 11.Tracking system performance of Intelligent 3 level PID gain selector and 3 level Fuzzy logic controller

C. Intelligent 5 level PID gain selector and 5 level Fuzzy Logic Controller

The simulation time is conducted for 5 sec in which transient response is seen for 0-1 sec and steady state response for 4-5 sec. There seen improved performance of the Intelligent 5 level PID gain selector to Fuzzy system.

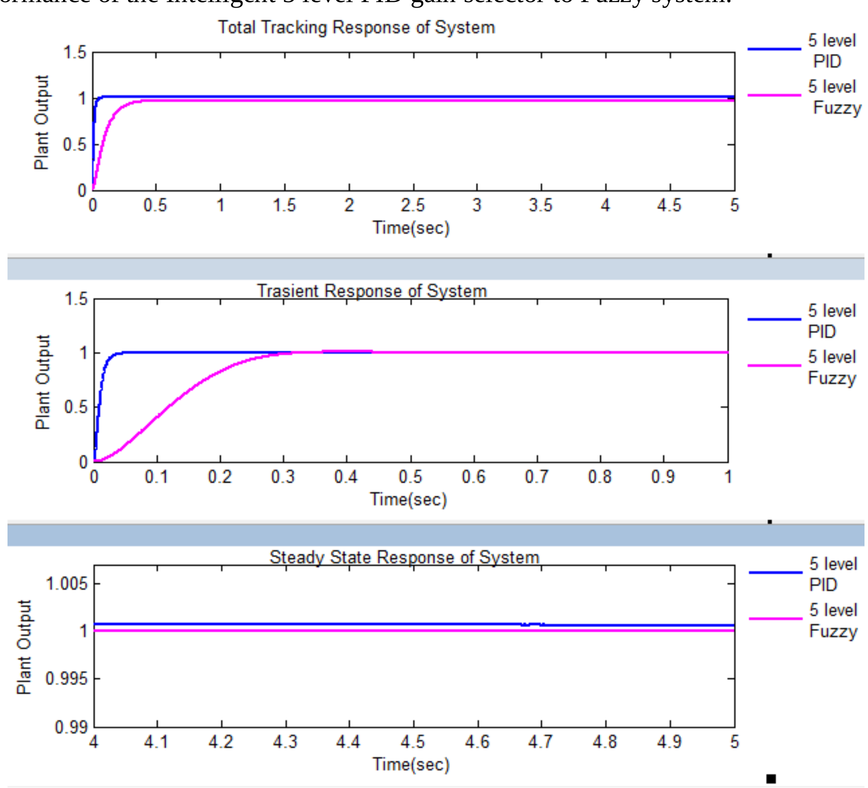

Figure 12**.** Tracking system performance of Intelligent 5 level PID gain selector and 5 level Fuzzy logic controller

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TABLE IX: TIME DOMAIN SPECIFICATIONS

Controllers	Overshoot (%)	Settling time (5% tolerance band)
Level 5 PID	1.24	0.058
Level 5 fuzzy	0.52	0.26
Level 3 PID	1.4	0.054
Level 3 Fuzzy	2.8	0.34
PID	1.32	0.13
MZN PID	37.23	0.09
ZN PID	98	0.41

From the time domain specifications it is understood that proposed model has superior performance with respect to overshoot and settling time.

D. Intelligent 3 level PID gain selector and 5 level PID gain selector with disturbance

A small step disturbance is been introduced into the system and its performance analysis is observed for a simulation time of 5 sec. The transient response is observed from 0-0.5 sec with a steady state response of time 2.9-3.2 sec and it is seen that the system progresses well

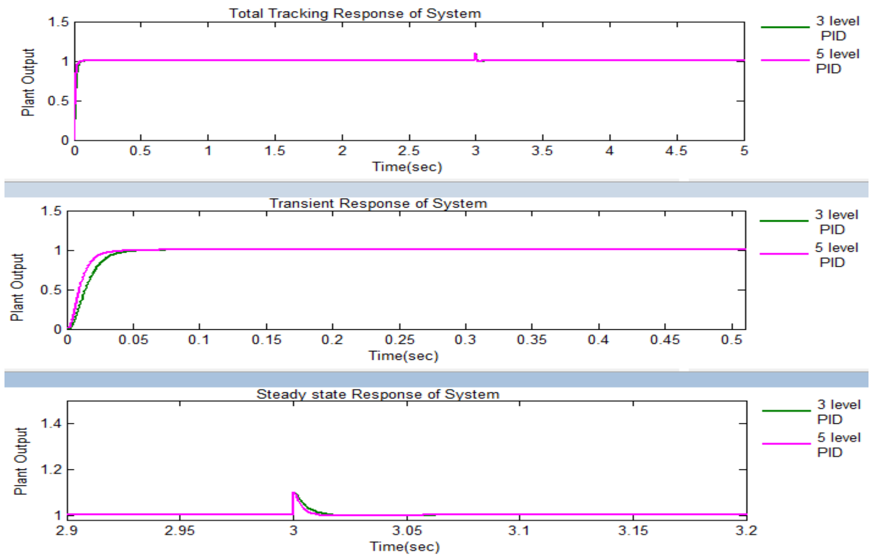

Figure 13.Tracking system performance of Intelligent 3 level,5 level PID gain selector with disturbance.

VII. CONCLUSION

This paper presents updation of constant gains of PID controller. In this context PID controller is tuned with well known Ziegler Nichols and Modified Ziegler Nichols tuning techniques. From the MATLAB simulations, Modified Ziegler Nichols tuned PID shows the better performance.

The merits of proposed work with respect to Fuzzy logic are – no requirement of membership functions, minimizing the number of rules and no necessary of defuzzification.

The proposed Intelligent PID selection using Max Min composition exhibits enhanced performance to Fuzzy logic controller is been presented with the help of simulations. It is observed with Intelligent 3 level, 5 level PID selector model shows improved performance in terms of overshoot and settling time than 3 level , 5 level Fuzzy logic controller.

VIII. ACKNOWLEDGMENT

I would like to express my sincere thanks to my guide P.Ramesh, Assistant Professor, EEE Dept and K.Veeresham , Associate Professor, EEE Dept for their valuable suggestions and guidance.

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