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Speed Control of DC Motor using Relay Feedback Tuned PI, Fuzzy PI and Self-Tuned Fuzzy PI Controller

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Abstract

Ziegler-Nichols tuned PI or PID controller performs well around normal working conditions, but its tolerance is severely affected to process parameter variations. In this paper the speed control of a DC motor is demonstrated by PI controller which is tuned by relay feedback test. To overcome the shortcomings of conventional controllers' artificial intelligent techniques can be adopted to design intelligent controllers like Fuzzy PI controller (FPIC) and Self-tuning Fuzzy PI controller (STFPIC), which may use in any linear, nonlinear and complex system without requirement to system mathematical model. The propose STFPIC adjusts the output scaling factor on-line by fuzzy rules according to the current trend of the controlled process, so that one can control the process more effectively. In this real time application of speed control of DC motor opto-coupler is used as output sensor of motor in place of generator, which measures output speed in terms of voltage. The designed model independent controllers showed improved performance to control the speed of the motor.

Keywords: Conventional control, Relay-feedback test, DC Motor, Self-tuning fuzzy PI controller.

1. Introduction

High performance DC motor drives are used extensively in industrial applications for its good starting and braking performance. The DC motor drive is a highly controllable electrical motor drive suitable for robotic manipulators, guided vehicles, steel mills, mining machines; mine hoist machines and electrical traction. Usually, precise, fast, effective speed references tracking with minimum overshoot/undershoot and small steady state error are essential control objectives of such a drive system. The purpose of DC motor speed controller is to generate a signal representing the demanded speed, and to drive the motor at that speed.

The conventional PID controllers are widely used in industry due to their simplicity in arithmetic, ease of using, good robustness, high reliability, stabilization and zero steady state error. Usually conventional controllers are used in motors drive [1-4]. But the performances of the classical controllers are not up to the mark due to the following shortcomings: a) Unavailability of proper mathematical modeling [5, 6]. b) Drives are nonlinear systems thus the performance of classical controller is not satisfactory [2, 6]. c) The response due to parameter variation and set point variation is poor in classical control. Nowadays, relay feedback test have received a great deal of importance in controller tuning. Åström and Hägglund suggested the use of an ideal (on-off) relay to generate sustained oscillation in closed loop system identification. In this paper, relay feedback test is performed on the motor to find out the tuning parameter of the PI controller.

It has been reported that fuzzy logic controller is very suitable for non-linear system and even with unknown structure [7, 8]. In [9-20], various fuzzy PI / PID hybrid control schemes are discussed to improve PI / PID control performance. The tuning procedure can be a time-consuming, expensive and difficult task [21]. This problem can be easily eliminated by using self-tuning scheme for fuzzy PI / PID controller.

Generally a skilled human operator always tries to manipulate the process input, usually by adjusting the controller gain based on the current process states (error and change of error) to get the process "optimally" controlled. A simple but robust self-tuning scheme is used here, where the controller gain is adjusted continuously with the help of fuzzy rules. The tuning of the output-scaling factor (SF) that is equivalent to the controller gain has been given the highest priority because of its strong influence on the performance and stability of the system [22, 23]. The self-tuning mechanism is applied to PI type fuzzy logic controller for speed control of motor.

The controller that controls the speed of the DC motor is developed through programming using C++ language. The whole system is designed by assembling the following parts: Computer (Controller), DAC, Buffer, Driver, DC Motor, Opto-Coupler, Single Channel DAS, Transistor and F/V Converter.

The rest of the paper is presented in following sections: FPIC and STFPIC are described in the first section. In the second part FPIC, STFPIC and Relay feedback tuned PI controller are demonstrated to control the speed of a DC motor. Finally conclusion is made in section 4.

2. Development of PI-type Self-Tuning fuzzy Controller

The basic function of the rule base is to represent in a structured way the control policy of an experienced process operator and / or control engineer in the form of a set of production rules.

Considered a set of desired input-output data pairs: $[x_1^{(1)}, x_2^{(1)}, u^{(1)}]$ and $[x_1^{(2)}, x_2^{(2)}, u^{(2)}]$ --------(1)

Where x_1 and x_2 are input data represents error (e) and change of error (Δe) and u stands for output data. The task here is to generate a set of fuzzy rules from the desired input-output pairs of equation (1) through following steps [22 - 24]:

Divide the input and output spaces into 7 fuzzy regions and assigned membership functions. Assumed the domain intervals of x_1 and x_2 and u are [-1, +1]. The term sets of e, Δe and u contains the same linguistic expressions for the magnitude part of the linguistic values, i.e., *LE* = *L*ΔE = *LU* = {NB, NM, NS, ZE, PS, PM, PB} as shown in Figure 1 and represents the rule base in the table format as shown in Table 1. The cell defined by the intersection of the first row and the first column represents a rule such as,

If e(k) is NM and Δe(k) is PS then u(k) is NS.

The fuzzy controller is developed using this 49 fuzzy if-then rules as shown in Table 1.

Similar like fuzzy controller, using symmetrical triangle, calculate membership functions of (i) e, Δe and u (as shown in Figure 1) and (ii) gain updating factor (β) (as shown in Figure 2) for self-tuning mechanism. An additional logic for addition at the output of controller is incorporated for PI controller as shown in Figure 3. Because the discrete-time version equation of PI controller is: u(k) = Δu(k) + u(k-1).

Figure 3 shows that the output scaling-factor (SF) of the fuzzy controller is modified by a self-tuning mechanism, gain-updating factor (β). After the FPIC rule determination, developed the rule base for gain updating factor, in the similar way like: *if e is E and Δe is ΔE then β isβ.* A structure of which is shown in Table 2, though it may vary. Further modification of the rule base for β may be required, depending on the type of response the control system designer wishes to achieve. As shown in Figure 3, when this β is multiplied with the fuzzy controller gain G_u, gives the overall gain of STFPIC. It is very important to note that the rule base for computation of β will always be dependent on the choice of the rule base for the controller.

2.1 Brief Description of Experimental Set-up

In the propose speed control application as shown in Figure 4 and Figure 5, a slotted rotary encoder is mounted at the motor (Manufacturer: SHINKO ELECTRIC CO. LTD., Japan; Speed: 1500 R.P.M.) shaft wheel. Infra-red LED was obscured from the view of photodiode by the restrictions of the wheels so that a series of pulses with a frequency proportional to motor speed is available. The frequency signal is converted into voltage signal by F/V converter that is found to be linear in nature as shown in Figure 6.

An appropriate transfer function model of motor can be obtained from the step test by using parameter estimation methods. For processes that have monotonically increasing step responses due to a step change, such as shown in Figure 7, FOPDT models are appropriate. From the resulting process reaction curve the model parameters can be calculated as:

Steady state gain (K) = $\Delta x/\Delta m$ = 3.8/4.0=0.95; θ = 0.09 and τ = (0.42-0.09)=0.33 sec.

Substituting these values obtained the FOPDT model of DC motor: $G(s)=0.95e^{-0.09s}/(0.33s+1)$

3. Results

In this section, the performance of designed controllers is evaluated for motor speed control. Different performance criterion such as rising time (t_r), settling time (t_s), peak time (t_p), % peak overshoot (%OS), integral absolute error (IAE) and integral of the time multiplied absolute error (ITAE) are studied to analyze the performance of different controllers.

3.1 PI Controller

Åström and Hägglund auto-tuner [25] is based on the observation that a feedback system in which output (y) lags behind the input (u) by $-\pi$ radian may oscillate with a period P_u. Here, the test is carried on the motor in its running condition. To generate the sustained oscillation, a relay-feedback test as shown in the Figure 8 and Figure 9, is performed on the motor by increasing and decreasing the input (u) by h. The ultimate gain (K_u) and ultimate frequency (ω_u) can be found easily from the principal harmonic approximation as represent by equ^n.(2) and (3) Where α is the amplitude of oscillation. From there, calculated the controller gain (K_p) and integral action time (T_i) of a PI controller by applying Ziegler-Nichols method shown by equ^n. (4) and (5).

$K_u=4h/\pi\alpha$ ------ (2); $\omega_u=P_u/2\pi$ ------ (3); $K_p=K_u/2.2$ ------ (4); $T_i=P_u/1.2$ ------ (5)

K_p of 0.526 and T_i of 3.125 are measured through the relay feedback test used to design the Relay Feedback Tuned PI Controller (RFTPIC), which is applied to the DC motor. The response of the motor for a set point of 3.88 volt is shown in Figure 10. The response shows a rise time of 2.26 sec. and it settled within a minute. But the RFTPI controller in long run shows some significant IAE and ITAE value due to its steady state error.

3.2 Fuzzy PI Controller

The motor response for same set point is shown in Figure 11 viewed, when Fuzzy PI controller is used in place of RFTPI controller. Here the rise time and settling time is almost similar to as RFTPI controller, but observed less ripple in the characteristic curve, thus observed lesser IAE and ITAE values. Though overshoot is remain same, FPIC decreased peak time by 2.41 sec.

3.3 Self-Tuning Fuzzy PI Controller

In the last section, to control the speed of the motor, the self-tuning mechanism is added with the applied fuzzy PI controller. In order to demonstrate the effectiveness and robustness character of the proposed STFPIC implied it to the same motor at same set point. For that the motor characteristic curve observed is shown in Figure 12. From the Table 3, it can be observed an overall improved performance of STFPIC. The controller gives a comparable rise time with respect to RFTPIC and FPIC. However, STFPIC gives very low peak time, peak overshoot and it settles within 31.75 sec. The STFPIC also outperforms the PI and FPIC with respect to IAE and ITAE. Due to its self-tuning mechanism, controller always tracks the desired value of motor speed, thus gives zero steady state error and negligible IAE and ITAE.

4. Conclusion

One of the highlights of the proposed scheme is relay feedback tuning, which is performed on-line on the motor as shown in Figure 8. Tuning done by relay feedback test for PI controller performs well to control the speed of motor. Even fuzzy PI controller controls the motor effectively. The STFPIC method used here is rather simple to understand by the control engineer. The results show that the STFPI controller improved the process performance by minimizing the steady state error and other performance criterions. This scheme differs from others as it attempts to implement the operator's strategy while running a practical system, not a simulated one. The operators / control engineers can easily design the fuzzy rule base for fuzzy controller and as well as the fuzzy rule base for gain updating factor according to their knowledge in the running condition. Apart from this practical system, these controllers are tested in various 1st and 2nd order linear and nonlinear models also. Though we have identified the FOPDT model of the motor for verification but importantly, the designed controllers can perform without knowing the system mathematical model also.

References

[1] F.D.S.Cardoso, J.F.Martins and V.F.Pires(1998), "A Comparative Study of a PI, Neural Network and Fuzzy Genetic Approach Controllers for an AC Drive" *5th International Workshop on Advanced Motion Control*, pp.375 –380.

[2] Ye Zhongming, Wu Bin (2000), "A Review on Induction Motor Online Fault Diagnosis" *The Third International Power Electronics and Motion Control Conference Proceedings.*, **3**, pp.1353 -1358.

[3] R.Echavarria, S.Horta, M.Oliver (1995), "A Three Phase Motor Drive Using IGBTs and Constant V/F Speed Control with Slip Regulation", *IV IEEE International Power Electronics Congress, Technical Proceedings*, pp.87 -91.

[4] A.Munoz-Garcia, T.A.Lipo, D.W.Novotny (1998), "A New Induction Motor V/f Control Method Capable of High-Performance Regulation at Low Speeds", *IEEE Transactions On Industry Application*, **34**, pp.813 -821.

[5] B.K.Bose (1997), "Intelligent Control and Estimation in Power Electronics and Drives", *IEEE International Electric Machines and Drives Conference Record*, pp. TA2/2.1 -TA2/2.6.

[6] T.G.Habetler, R.G.Harley (2001), "Power Electronic Converter and System Control", *Proceedings of the IEEE*, **89**, pp.913 –925.

[7] R. R. Yager, L. A. Zadeh (Eds.) (1992), "An introduction to Fuzzy logic application in intelligent systems," *Kluwer*, Boston, MA.

[8] H. J. Zimmermann (1993), "Fuzzy sets theory and its applications." *Kluwer*, Nijhoa, Boston, Dordrecht, Lancaster, Singapore: World Scientific.

[9] Kim J-H, Kim K-C, Chong EKP (1994), "Fuzzy precompensated PID controllers", *IEEE Trans. Con. Syst. Technology*, **2**(4).

[10] Cho Hyun-Joon, Cho Kwang-Bo, Wang Bo- Hyeun (1997), "Fuzzy-PID hybrid control: automatic rule generation using genetic algorithm", *Fuzzy sets and systems*, **92**(3), pp.305-316.

[11] Wu Zhi Qiao, Masaharu Mizumoto (1996), *Fuzzy sets and systems*, **78**, pp. 23-35.

[12] M. Sugeno (1985), "Industrial applications of Fuzzy Control", *Elsevier*, Amsterdam, Netherlands.

[13] M. Sugeno and K. Tanaka (1991), "Successive identification of a fuzzy model and its application to prediction of a complex system,", *Fuzzy Sets Syst.*, **42**, pp. 315 – 334.

[14] M. Sugeno and T. Yasukawa (1993), "A fuzzy–logic- based approach to qualitative modeling", *IEEE Trans. Fuzzy Syst.*, **1**, pp. 7 – 31.

[15] R. M. Tong (1979), "The construction and evaluation of fuzzy models", *in advances in Fuzzy Set Theory and applications ed. M. M. Gupta et. al.*, North Holland.

[16] R. Palm (1992), "Sliding mode fuzzy control", *in Proc. Fuzz IEEE*, San Diego, CA, pp. 519-526.

[17] T.Takagi and M. Sugeno (1985), "Fuzzy identification of systems and its applications to modeling and control", *IEEE Trans. Syst., Man, Cybern*. **15**.

[18] W. Pedrycz (1984), "An identification algorithm in fuzzy relational systems", *Fuzzy Sets Syst.*, **13**, pp. 153 – 167.

[19] W. Pedrycz and J. V. de Oliveira (1996), "Optimization of fuzzy models", *IEEE Trans. Syst., Man, Cyber*., **26**(4).

[20] R. Alcala, J. Casillas, O. Cordon, A. Gonzalez, and F. Herrera (2005), "A genetic rule weighting and selection process for fuzzy control of heating, ventilation and air conditioning systems", *Engineering application of Artificial Intelligence*, **28**, pp. 279 – 296.

[21] Qiang Xiong, Wen-Jian Cai and Ming He (2006), "A practical decentralized PID auto-tuning method for TITO systems under closed –loop control", *International Journal of Innovative Computing, Information and Control,* **2**(2).

[22] R.K.Mudi and N.R.Pal (1999), "A robust self-tuning scheme for PI and PD type fuzzy controllers", *IEEE trans. on fuzzy sys*. , **7**(1).

[23] A.K.Pal and R.K.Mudi (2008), "Self-Tuning Fuzzy PI controller and its application to HVAC system", *IJCC (US),* **6**(1).

[24] D. Dirankov, H. Hellendorn and M. Reintrank (1993), "An introduction to Fuzzy Control", New York: *Spinger-Verlag*.

[25] H.P.Haung, J.C.Jeng and K.Y.Luo (2005), "Auto-tune system using single-run relay feedback test and model-based controller design", *Journal of Process Control*, **15**.

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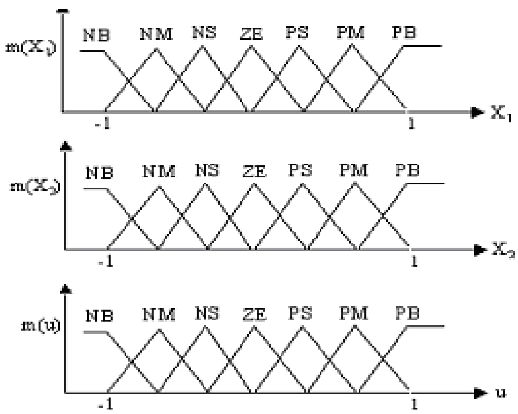

Figure 1: Membership function of inputs x_1, x_2 and output u

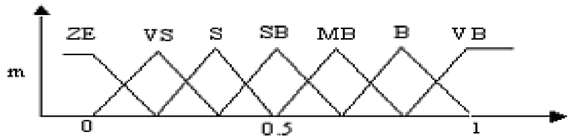

Figure 2: Membership function of gain updating factor β

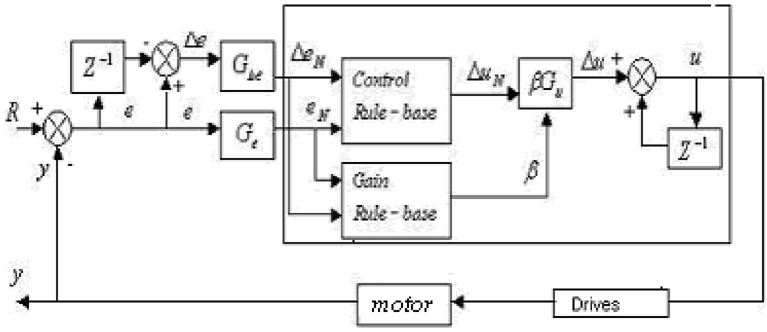

Figure 3: Block Diagram of STFPIC

Fig.4: Motor shaft with opto- coupler assembly

Figure 5: Experimental set-ups for speed control of DC motor (Heritage Institute of Technology R&D Lab.)

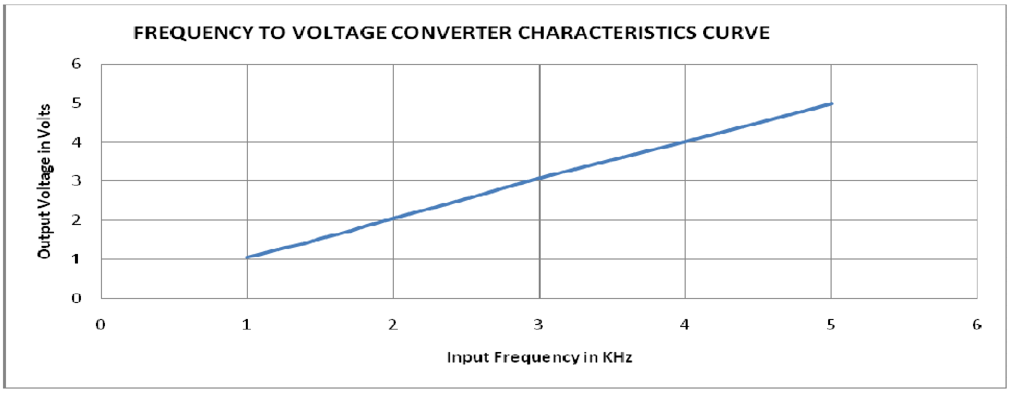

Figure 6: Frequency (proportional to motor speed) vs. voltage curve

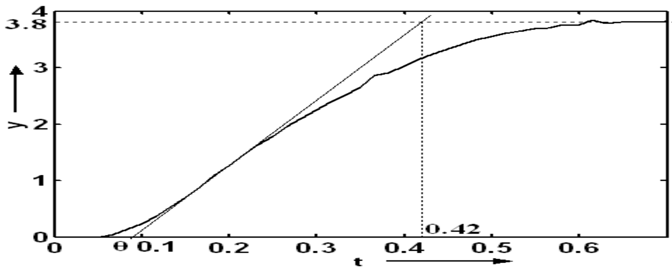

Figure 7: Step response of DC motor

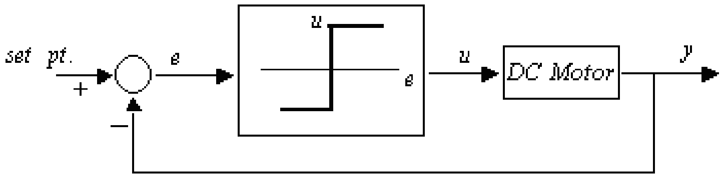

Figure 8: Block Diagram of relay-feedback test

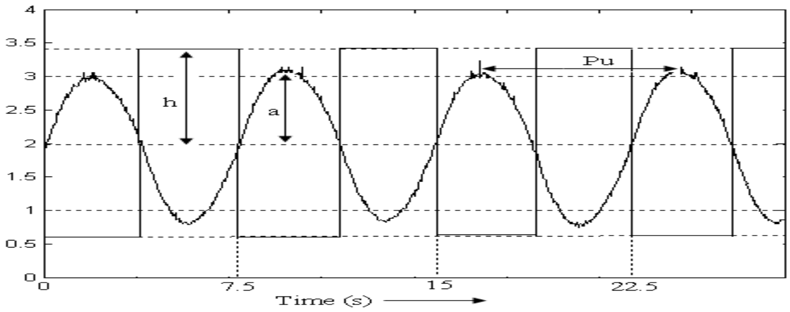

Figure 9**:** Relay feedback system response of a DC motor in close loop

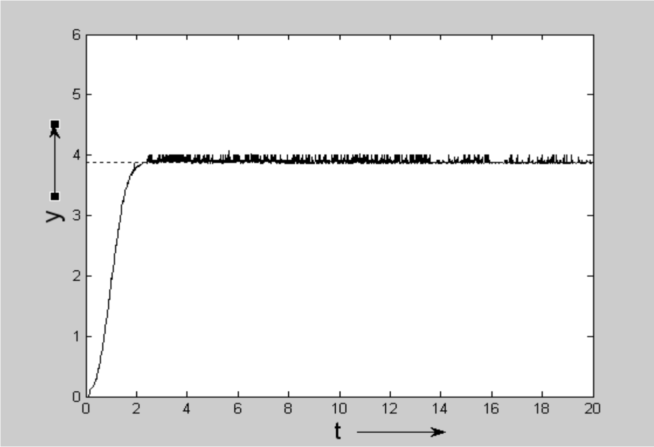

Figure 10: Characteristic curve of DC motor for RFTPI controller (y in volt, proportional to speed)

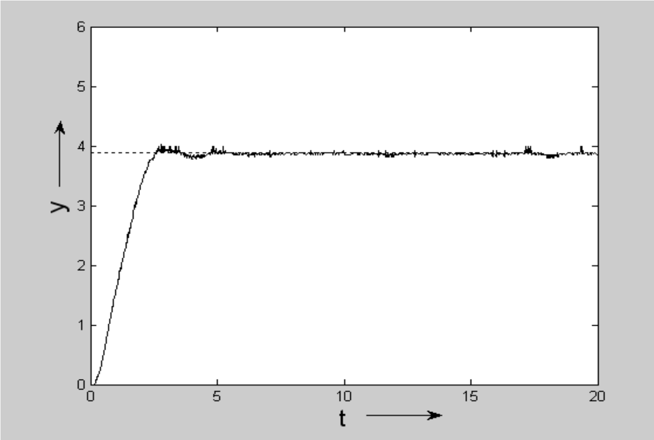

Figure 11: Characteristic curve of DC motor for FPI controller

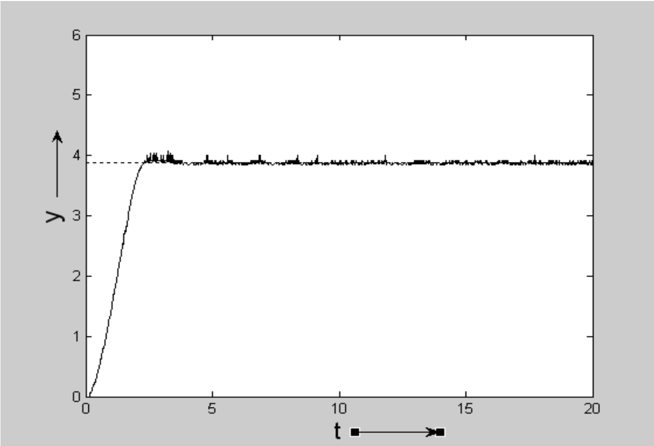

Figure 12: Characteristic curve of DC motor for STFPI controller

Table 1. Fuzzy rules for computation of u

$\Delta e / e$	*NB*	*NM*	*NS*	*ZE*	*PS*	*PM*	*PB*
NB	*NB*	*NB*	*NB*	*NM*	*NS*	*NS*	*ZE*
NM	*NB*	*NM*	*NM*	*NM*	*NS*	*ZE*	*PS*
NS	*NB*	*NM*	*NS*	*NS*	*ZE*	*PS*	*PM*
ZE	*NB*	*NM*	*NS*	*ZE*	*PS*	*PM*	*PB*
PS	*NM*	*NS*	*ZE*	*PS*	*PS*	*PM*	*PB*
PM	*NS*	*ZE*	*PS*	*PM*	*PM*	*PM*	*PB*
PB	*ZE*	*PS*	*PS*	*PM*	*PB*	*PB*	*PB*

Table 2. Rule Base for determination of β

$\Delta e / e$	*NB*	*NM*	*NS*	*ZE*	*PS*	*PM*	*PB*
NB	*VB*	*VB*	*VB*	*B*	*SB*	*S*	*ZE*
NM	*VB*	*VB*	*B*	*B*	*MB*	*S*	*VS*
NS	*VB*	*MB*	*B*	*VB*	*VS*	*S*	*VS*
ZE	*S*	*SB*	*MB*	*ZE*	*MB*	*SB*	*S*
PS	*VS*	*S*	*VS*	*VB*	*B*	*MB*	*VB*
PM	*VS*	*S*	*MB*	*B*	*B*	*VB*	*VB*
PB	*ZE*	*S*	*SB*	*B*	*VB*	*VB*	*VB*

Table 3: Performance comparison table for developed controllers

Controller Type	t_r(sec.)	t_p(sec.)	t_s(sec.)	%OS
RFTPIC	2.26	5.66	58.28	5.1
FPIC	2.29	3.25	55.83	5.1
STFPIC	2.62	2.82	31.75	3.6