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# Study of Interval type-2 Fuzzy proportional integration and derivative controller for continuous stirred tank reactor

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**Abstract**: This paper proposes interval type 2 fuzzy proportional–integral–derivative controller plan technique and it is connected to the non-straight framework continuous stirred tank reactor. Interval type-2 fuzzy controller is composed such way that it is autonomous of process. To comprehend the impact of impression of uncertainty on the controller's execution to two type of control bend to be specific forceful and smoother control bend are outlined. Popov-Lyapunov technique is utilized to discover stability of the framework.

**Keywords**: Interval type 2 fuzzy, continuous stirred tank reactor.

## I. INTRODUCTION

In industry we as a whole realize that the most normally utilized controllers are regular proportional–integral–derivative controller since they are basic in structure and have low cost [1]. In [2], different proportional–integral–derivative controller tuning strategies have been affirmed. Ziegler and Nichols, Cohen and Coon, Internal Model Control, Pole Placement Design Strategies are a portion of the outline systems. The use of proportional integral and derivative controllers in controlling direct framework may be a successful approach to accomplish wanted execution, yet proportional–integral–derivative controller won't not give palatable execution when the procedures have questionable model or the procedure is non-linear.

It has been determined in [3] that Type 1-Fuzzy Logic Controllers can be actualized with single, two, or three sources of info. Despite the fact that the significant research chip away at fuzzy proportional–integral–derivative controller fixates on the customary two-input PI or PD sort controller proposed by Mamdani, in various works it has been demonstrated that solitary information Type 1-Fuzzy Logic Controllers offer more noteworthy adaptability and better useful properties. Fuzzy controllers can be grouped into three sorts: the gain scheduling (gain scheduling), the immediate activity (DA) sort, and a mix of DA and gain scheduling sorts. The DA sort generally utilized as a part of fuzzy proportional–integral–derivative controller application; here in the criticism control circle fuzzy proportional–integral–derivative controller is put, and the proportional–integral–derivative controller activities computed utilizing fuzzy derivation. In gain scheduling sort controllers, singular proportional–integral–derivative controller picks up are figured through fuzzy deduction.

As of late, the fundamental research concentrate is on interval type-2 fuzzy logic controller. For the most part, interval type-2 fuzzy logic controller finish prevalent exhibitions as they give extra level of opportunity gave by the impression of vulnerability in their interval type-2 fuzzy sets. Key contrasts between interval type 2 and Type 1 interval fuzzy logic controller are Adaptive-ness, implying that the installed Type 1 fuzzy sets used to register the limits of the type-decreased interval change as information changes; and Novelty, implying that the upper and lower enrolment elements of a similar interval type-2 fuzzy set might be utilized at the same time in processing each bound of the type-lessened interval. Type 1 Fuzzy logic controllers does not have these properties; that is the reason a type-1 fuzzy logic controller can't execute the intricate control surface of an interval type-2 fuzzy logic controller utilizing a similar manage base. The interior structure of the interval type-2 fuzzy logic controller is similar to its type 1 partner. Principle distinction is that there is an additional type reduction system since interval type-2 fuzzy logic controller utilize and process interval type-2 fuzzy sets. A few investigations have been introduced to examine the impact of the footprint of uncertainty and additional type reduction process on wanted fuzzy enrolment (i.e., control surface) [5]. the type-2 fuzzy mapping [4].

Desired FM Yet, usually, evolutionary algorithms have been employed to design interval type-2 fuzzy logic controller such that to generate (i.e., control surface) [5]. The primary weakness of this approach is that it doesn't clarify of how the footprint of uncertainty parameters influence the execution and vigour of the interval type-2 fuzzy logic controller [6]. In this way, determining the scientific structure of an interval type-2 fuzzy logic controller in the system of the nonlinear control may be an effective approach to look at it [7] – [8]. However, the orderly outline and strength examination of the interval type-2 fuzzy logic controller are as yet difficult issues because of its generally more intricate structure [9] – [10].

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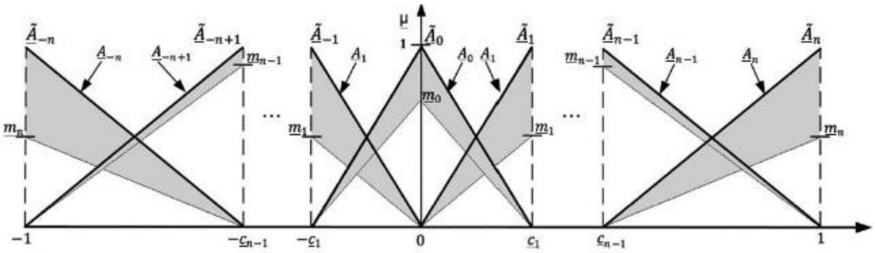

Fig.1 Illustration of the interval type-2 triangular MF for “e”.

## II. INTERVAL TYPE-2 FUZZY LOGIC CONTROLLER STRUCTURE

In this segment, the proposed interval type-2 fuzzy logic controller structures input yield mapping is determined. For effortlessness the precursor part for the interval type-2 fuzzy membership functions of the fuzzy run base is characterized by consistently conveyed symmetrical triangular. The e i.e. semantic estimations of the info are indicated as $\underline{\tilde{A}'}_i$ where i = {−n, (-n+1) . . . −1, 0, 1 . . .(n-1), n}. The characterized type-2 fuzzy set $(\tilde{A}'_i)$ are spoken to regarding lower membership function $\underline{\mu}'\underline{\tilde{A}'}_i)$ and upper membership function $\left(\overline{\mu}'\underline{\tilde{A}'}_i\right)$. As appeared in Fig.1, the tallness of the lower membership functions is spoken to by $\underline{m}_i$ though the center of the $\underline{\tilde{A}'}_i$ is indicated by $\underline{c}_i$. The input interval type-2 fuzzy sets are symmetrical, subsequently the information space (e) is separated in two fundamental districts which are named as Region-A (e ∈ $[\underline{c}_{-n}\ \ \underline{c}_0]$) and Region-B (e ∈ $[\underline{c}_{-n}\ \ \underline{c}_0]$). In addition, following properties are controlled by the characterized interval type-2 fuzzy membership functions:

(i) $\overline{\mu}'\underline{\tilde{A}}_i'(\mathrm{e}) + \overline{\mu}'\underline{\tilde{A}'}_{i+1}(\mathrm{e}) = 1$ , i = -n, . . .,+n

(ii) $\underline{\mu}'\underline{\tilde{A}}_i'(\mathrm{e}) = \underline{m}_i{'}{*}\ \overline{\mu}'\underline{\tilde{A}}_i'(\mathrm{e})$ , i = -n, . . . ,+n

(iii) $\underline{m}_{-i} = \underline{m}_i{'}$ , i = 1, . . . ,n

The proposed interval type-2 fuzzy logic controller run development is described as:

$$r_i\text{: IF e is } \underline{\tilde{A}'}_i \text{ THEN } \underline{e'}_{fuz} \text{ is } \underline{B}_i,\quad i = 1, \ldots, N \qquad (1)$$

The aggregate number of tenets is given as N = 2n + 1, while the resultant part deciphers the crisp singleton esteems (Bi) which are consistently disseminated in the scope of [−1, 1]. Liang and Mendel demonstrated that the de-fuzzified yield of an interval type-2 fuzzy logic controller can be computed as:

$$\underline{e'}_{fuz} = \frac{\underline{e}^{l\prime}{}_{fuz} + \underline{e}^{r\prime}{}_{fuz}}{2} \qquad (2)$$

where $\underline{e}^{r\prime}{}_{fuz}$ and $\underline{e}^{l\prime}{}_{fuz}$ are the end points of the type reduced set.

$\underline{e}^{r'}{}_{fuz}$ And $\underline{e}^{l'}{}_{fuz}$ are calculated as follows:

$$\underline{e}^{r\prime}{}_{fuz} = \frac{\sum_{j=R+1}^{N} \overline{\mu}'\underline{\tilde{A}'}_i(\mathrm{e}) * \underline{B}_i + \sum_{j=1}^{R} \underline{\mu}'\underline{\tilde{A}'}_i(\mathrm{e}) * \underline{B}_i}{\sum_{j=R+1}^{N} \overline{\mu}'\underline{\tilde{A}'}_i(\mathrm{e}) + \sum_{j=1}^{R} \underline{\mu}'\underline{\tilde{A}'}_i(\mathrm{e})} \qquad (3)$$

$$\underline{e}^{l'}{}_{fuz} = \frac{\sum_{j=1}^{L} \overline{\mu}'\underline{\tilde{A}'}_i(\mathrm{e}) * \underline{B}_i + \sum_{j=L+1}^{N} \underline{\mu}'\underline{\tilde{A}'}_i(\mathrm{e}) * \underline{B}_i}{\sum_{j=1}^{L} \overline{\mu}'\underline{\tilde{A}'}_i(\mathrm{e}) + \sum_{j=L+1}^{N} \underline{\mu}'\underline{\tilde{A}'}_i(\mathrm{e})} \qquad (4)$$

Here, (R, L) is the arrangement set with the end goal that which amplify/limit separately. Completely covering triangular interval type-2 fuzzy sets in the feeling of upper and lower fuzzy enrollment capacities are utilized as a part of interval type-2 fuzzy logic controller. Subsequently, it can be constantly ensured that a crisp estimation of "e" has a place with two progressive IT2-FSs, i.e. $\underline{\tilde{A}'}_i$ and $\underline{\tilde{A}'}_{i+1}$. Subsequently, since for any crisp information just two tenets (N=2) are constantly enacted as the exchanging focuses (R, L) are constantly equivalent to "1". A shut shape connection of the interval type-2 fuzzy logic controller can be gotten from this. The type decreased can be determined as:

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$$\underline{e}^{l'}{}_{fuz} = \frac{\overline{\mu}'\widetilde{A}'_i(\mathrm{e})*\underline{B}_i+\underline{\mu}'\widetilde{A}'_{i+1}(\mathrm{e})*\underline{B}_{i+1}}{\overline{\mu}'\widetilde{A}'_i(\mathrm{e})+\underline{\mu}'\widetilde{A}'_{i+1}(\mathrm{e})}$$

$$\underline{e}^{r'}{}_{fuz} = \frac{\underline{\mu}'\widetilde{A}'_i(\mathrm{e})*\underline{B}_i+\overline{\mu}'\widetilde{A}'_{i+1}(\mathrm{e})*\underline{B}_{i+1}}{\overline{\mu}'\widetilde{A}'_{i+1}(\mathrm{e})+\underline{\mu}'\widetilde{A}'_i(\mathrm{e})} \qquad (5)$$

After replacing (5) in (2), proposed type-2 fuzzy controllers closed form mapping is obtained. Following are the properties of the presented an interval type-2 fuzzy logic controller output.
As for the information 'e', $\underline{e}'_{fuz}$ has a constant capacity.
With reference the info 'e', $\underline{e}'_{fuz}$ has a symmetrical capacity, i.e. $\underline{e}'_{fuz}(e) = -\underline{e}'_{fuz}(-e)$.
In the event that the information blunder equivalents to zero then fuzzified mistake equivalents to be zero. This is compulsory to have zero enduring state blunder. i.e. (e) =0 then $\underline{e}'_{fuz} = 0$

## III. INTERVAL TYPE 2-FUZZY CONTROLLER DESIGN STRATEGY

In this area, the outline procedure for the single information interval type-2 fuzzy controller is introduced. Yield can be unmistakably spoken to in the blunder area on the grounds that the interval type-2 fuzzy controller comprises of a solitary info. This disentangles the plan technique for interval type-2 fuzzy logic controller to the age of non-straight control bend, rather than control bend outline. In this strategy, plan parameters are considered from the statures ($\underline{m}_i$) of lower membership elements of $'\underline{\widetilde{A}'}_i$. Fundamentally, the plan parameters impact on the interval type-2 fuzzy logic controller yield are broke down and after that a procedure free outline technique to produce control bends is proposed. For straightforwardness, we initially determine a shut type of a "three rule" type-2 fuzzy induction and afterward the examination for outline parameters impacts is done in detail. The parameters for interval type-2 fuzzy logic controller structure are set as $\underline{B}_{-1}= -1$, $\underline{B}_{+1} = +1$, $\underline{B}_0 = 0$, $\underline{C}_{-1}= -1$, $\underline{C}_{+1} = +1$ and $\underline{C}_0 = 0$ [11]. For the information Region-A (e ∈ [−1, 0]), the end purposes of the type decreased set would then be able to be inferred as takes after:

$$\underline{e}^{l'}{}_{fuz} = \frac{-\overline{\mu}'\widetilde{A}'_{-1}(\mathrm{e})}{\overline{\mu}'\widetilde{A}'_{-1}(\mathrm{e})+\underline{\mu}'\widetilde{A}'_0(\mathrm{e})}\ ,\quad \underline{e}^{r'}{}_{fuz} = \frac{-\underline{\mu}'\widetilde{A}'_{-1}(\mathrm{e})}{\overline{\mu}'\widetilde{A}'_0(\mathrm{e})+\underline{\mu}'\widetilde{A}'_{-1}(\mathrm{e})} \qquad (6)$$

For the Region-B (e ∈ [0, +1]), the end points of the type reduced set reduces to:

$$\underline{e}^{l'}{}_{fuz} = \frac{\overline{\mu}'\widetilde{A}'_1(\mathrm{e})}{\overline{\mu}'\widetilde{A}'_0(\mathrm{e})+\underline{\mu}'\widetilde{A}'_1(\mathrm{e})}\ ,\quad \underline{e}^{r'}{}_{fuz} = \frac{\underline{\mu}'\widetilde{A}'_1(\mathrm{e})}{\overline{\mu}'\widetilde{A}'_0(\mathrm{e})+\underline{\mu}'\widetilde{A}'_1(\mathrm{e})} \qquad (7)$$

TABLE 1: EXPRESSIONS OF $\underline{e}^{l}{}_{fuz}$ AND $\underline{e}^{r}{}_{fuz}$

| | Region-A e ∈ [−1, 0] | Region-B e ∈ [0,+1] |
|---|---|---|
| $\underline{e}^{l'}{}_{fuz}$ | $\frac{-\overline{\mu}'\widetilde{A}'_{-1}(\mathrm{e})}{\overline{\mu}'\widetilde{A}'_{-1}(\mathrm{e}) + \underline{\mu}'\widetilde{A}'_0(\mathrm{e})}$ | $\frac{\overline{\mu}'\widetilde{A}'_1(\mathrm{e})}{\overline{\mu}'\widetilde{A}'_0(\mathrm{e}) + \underline{\mu}'\widetilde{A}'_1(\mathrm{e})}$ |
| $\underline{e}^{r'}{}_{fuz}$ | $\frac{-\underline{\mu}'\widetilde{A}'_{-1}(\mathrm{e})}{\overline{\mu}'\widetilde{A}'_0(\mathrm{e}) + \underline{\mu}'\widetilde{A}'_{-1}(\mathrm{e})}$ | $\frac{\underline{\mu}'\widetilde{A}'_1(\mathrm{e})}{\overline{\mu}'\widetilde{A}'_0(\mathrm{e}) + \underline{\mu}'\widetilde{A}'_1(\mathrm{e})}$ |

To examine the impact of the outline parameters ($\underline{m}_{-1}$,$\underline{m}_0$,$\underline{m}_1$) on the yield effectively the inferred explanatory articulations of $\underline{e}^{l'}{}_{fuz}$ and $\underline{e}^{r'}{}_{fuz}$ fuz for a "three rule" interval type-2 fuzzy logic controller are organized in Table 1 . In this examination, just Region-B will be assessed in detail. In view of symmetrical and consistently disseminated nature of info and yield membership works, the examinations of Region-B can be reached out for Region-A. The accompanying meta-rules can be inferred to shape a control activity from the determined articulations of of $\underline{e}^{l'}{}_{fuz}$ and $\underline{e}^{r'}{}_{fuz}$ for Region-B, to get a palatable framework execution.

i. The estimation of $\underline{e}^{l'}{}_{fuz}$ diminishes/increments, if the estimation of $\overline{\mu}'\widetilde{A}'_1$(e) (i.e.$\underline{m}_1$) diminishes/increments separately.

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ii. The estimation of $\underline{e}^{r\prime}{}_{fuz}$ builds/diminishes, if the estimation of $\overline{\mu'\widetilde{A}'}_0$(e) (i.e. $\underline{m}_0$) diminishes/builds then individually. The de-fuzzified yield of an interval type-2 fuzzy logic controller ($\underline{e}'_{fuz}$ ) is the normal estimation of $\underline{e}^{r\prime}{}_{fuz}$ and $\underline{e}^{l'}{}_{fuz}$ esteems.

iii. A forceful control activity is gotten, if the estimation of $\underline{m}_1$ is expanded while $\underline{m}_0$ is diminished then the estimation of $\underline{e}'_{fuz}$ is expanded since the estimations of both $\underline{e}^{r'}{}_{fuz}$ and $\underline{e}^{l\prime}{}_{fuz}$ are expanded.

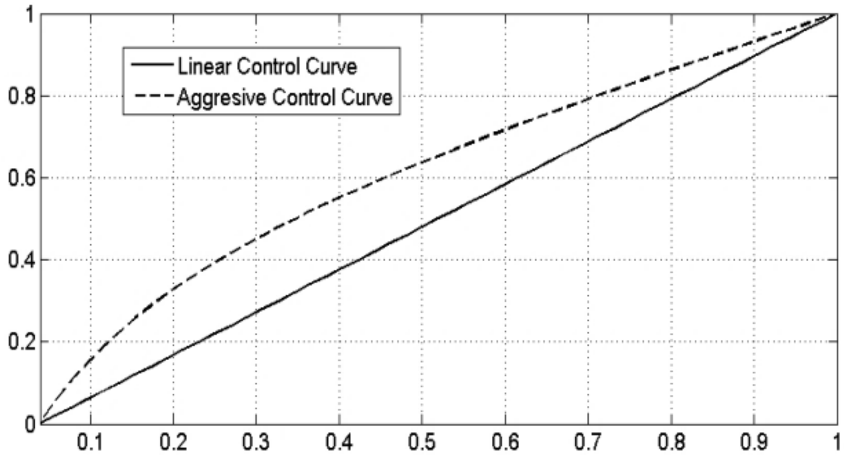


Fig.2: Linear control curve versus Aggressive control curve

iv. A smooth control activity is gotten if the estimation of $\underline{m}_1$ is diminished while $\underline{m}_0$ is expanded then the estimation of $\underline{e}'_{fuz}$ is diminished since the estimations of both $\underline{e}^{r'}{}_{fuz}$ and $\underline{e}^{l'}{}_{fuz}$ are diminished.

By choosing $\underline{m}_1$ moderately greater than m_0, a forceful nonlinear control activity can be produced i.e1≥ $\underline{m}_1 = \underline{m}_{-1} \geq \underline{m}_0 \geq 0$. To get forceful control bend, picking $\underline{m}_1 = \underline{m}_{-1}$ and $\underline{m}_0$ equivalent to 0.9 and 0.2 individually, the control bend showed in Fig.2. At the point when e is near "0" the control bend has a high affect ability. For quick transient framework reaction forceful control bend can be favoured. Be that as it may, particularly around the set point esteem, i.e. e=0 the created control bend is delicate to the clamours.

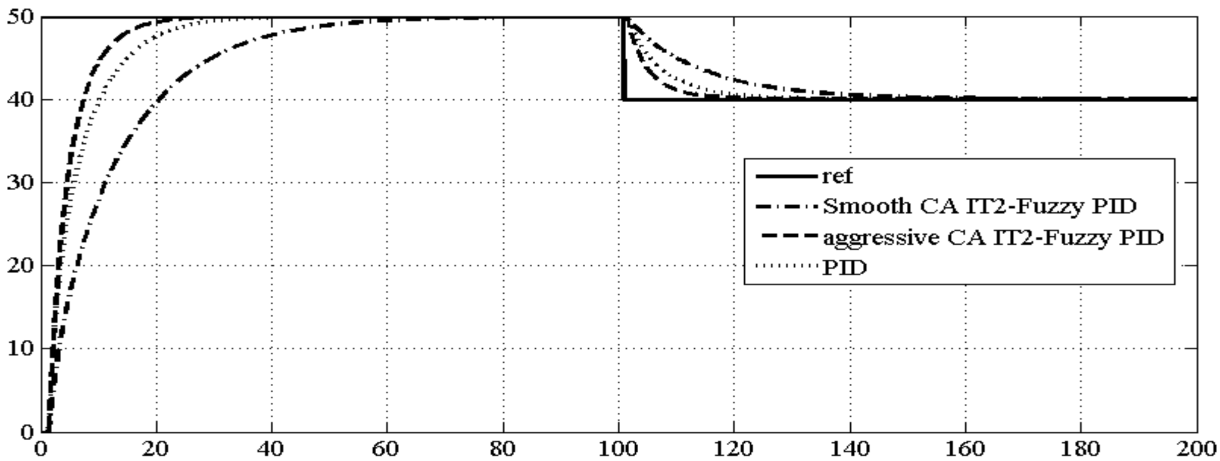


Fig.4. set point tracking of interval type-2 fuzzy logic controller and proportional integration and derivative controller

picking $\underline{m}_1 = \underline{m}_{-1}$ and $\underline{m}_0$ equivalent to 0.2 and 0.9 separately. At the point when e is near "0" it has low affectability. For vigorous shut circle control execution against parameter vulnerabilities and additionally background noises control bend can be favoured.

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## IV. SIMULATION RESULT AND STABILITY ANALYSIS

For computing Transfer capacity of continuous stirred tank reactor cooling process the progression reaction is thought about. For the progression reaction the info is step input, the underlying temperature is taken as $57^{o}$C and the set point is taken as $45^{o}$C. The procedure has expansive dead time and is exceptionally damped. Along these lines the progression reaction can be fitted into a basic first-arrange show with dead-time.

In this manner, the exchange capacity of the continuous stirred tank reactor procedure is given by:

$$\underline{G}(s) = \frac{0.12e^{-2s}}{3s+1} \qquad (8)$$

Tuning of proportional integration and derivative controller for continuous stirred tank reactor is finished by Ciancone relationship [12], it is turning out to be as per the following: $K_P$=6.667, $K_D = 2$ and $K_I = 1.9$. Re-enactment Result of continuous stirred tank reactor is appeared in fig.4 has examination between IT2 Fuzzy proportional integration and derivative with forceful, smooth control activity and proportional integration and derivative controller. At first step contribution of extent 50 is connected to the procedure following 100 second reference is changed to 40. It can be found in the fig.4 procedure reprocess with various types of controller can track the reference with various ascent time and settling time. Reaction because of Aggressive control activity Fuzzy controller has less ascent time contrasted with other controller; while reaction because of Smoother control activity Fuzzy controller has higher settling time contrasted with other controller execution. Table 2 indicates step reaction attributes of proportional integration and derivative and interval type-2 fuzzy logic controller; where step contribution of greatness 50 is connected to the procedure Type 1 Fuzzy membership work is upgraded by molecule swarm advancement technique, such fuzzy controller is connected to continuous stirred tank reactor and its reaction is contrasted and interval type-2 fuzzy logic controller it can be found in the Fig.5. Process reaction because of PSO fuzzy controller has less ascent time contrasted with different controllers reprocess yet PSO fuzzy controller offers ascend to wavering and overshoot, which is missing in the reactions because of IT2-Fuzzy controller.

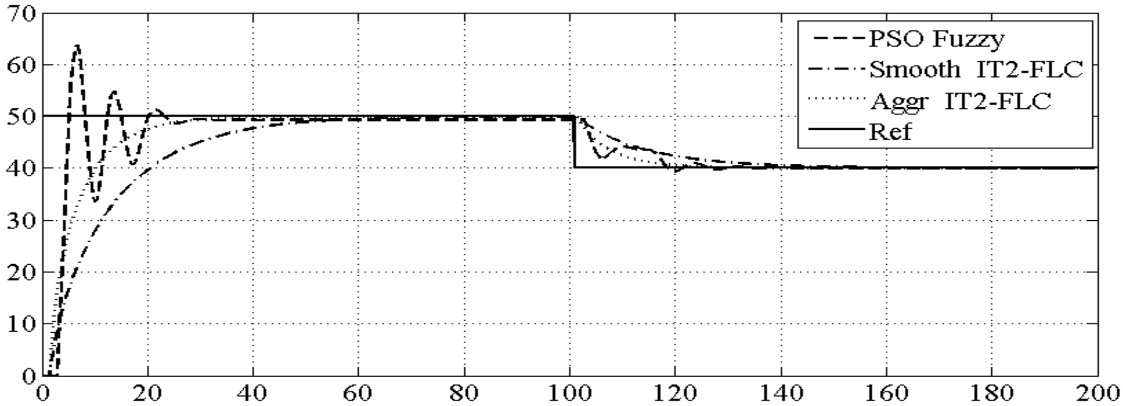


Fig.5 Comparison of interval type-2 fuzzy logic controller and Fuzzy PSO

A step response characteristic is shown in the Table 3. It can be seen that interval type-2 fuzzy logic controller without need of streamlining can beat the fuzzy PSO controller.

TABLE.2: STEP RESPONSE CHARACTERISTIC OF CONTINUOUS STIRRED TANK REACTOR WITH CONTROLLER

| | proportional integration and derivative | IT2-Fuzzy Aggressive | IT2-Fuzzy smooth |
|---|---|---|---|
| Rise Time(sec.) | 8.7525 | 5.3500 | 13.2419 |
| Settling Time(sec.) | 17.5525 | 9.0655 | 25.4256 |
| Settling Min | 45.0736 | 45.2042 | 45.0570 |
| Settling Max | 50.0000 | 50.0000 | 50.0000 |
| Overshoot (%) | 0 | 0 | 0 |
| Undershoot (%) | 0 | 0 | 0 |
| Peak | 50.0000 | 50.0000 | 50.0000 |

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TABLE.3: STEP RESPONSE CHARACTERISTIC OF CONTINUOUS STIRRED TANK REACTOR WITH CONTROLLER

| | TYPE 1-fuzzy PSO | IT2-Fuzzy Aggressive | IT2-Fuzzy smooth |
|---|---|---|---|
| Rise Time(sec.) | 1.7485 | 4.8370 | 13.6154 |
| Settling Time(sec.) | 25.9965 | 8.4840 | 25.8986 |
| Settling Min | 33.1110 | 36.0362 | 36.0020 |
| Settling Max | 53.6993 | 40.0000 | 40.0000 |
| Overshoot (%) | 34.2483 | 0 | 0 |
| Undershoot | 0 | 0 | 0 |
| Peak | 53.6993 | 40.0000 | 40.0000 |

To discover solidness of fuzzy framework utilizing Popov-Lyapunov technique first framework is changed over into bothered Lur'e framework [13], which is spoken to by exchange work as take after.

$$\underline{G}_{S-IT2}(s) = \frac{-0.1067S + 0.32}{S^2 + 1.269S + 0.525} \tag{8}$$

$$\underline{G}_{A-IT2}(s) = \frac{-0.1067S + 0.32}{S^2 + 1.226S + 0.653} \tag{9}$$

Exchange work $\underline{G}_{S-IT2}(s)$ speak to perturbed Lur'e arrangement of fuzzy framework which actualize smoother control activity while Transfer work $\underline{G}_{A-IT2}(s)$ speak to perturbed Lur'e arrangement of fuzzy framework which execute forceful control activity. Fig. 5 speak to Popov plot of the framework spoke to by exchange work (8), from that plot it can be closed as given framework fulfils Popov basis for slant of line $r \geq 1.45$. Correspondingly Popov plot of framework spoke to by (9) is appeared in Fig.6, from that it can be seen that given framework fulfils Popov basis for slant of line $r \geq 1.44$. Appling Lyapunov stability strategy P lattices are given as take after.

$$\underline{P}_{S-IT2} = \begin{bmatrix} 1.4766 & -0.1342 \\ -0.1342 & 0.4102 \end{bmatrix} \tag{10}$$

$$\underline{P}_{A-IT2} = \begin{bmatrix} 1.3204 & -0.3408 \\ -0.3486 & 0.2845 \end{bmatrix} \tag{11}$$

Given $\underline{P}$ frameworks are symmetric positive-definite, from this popov measure and Lyapunov stability technique its can be inferred that harmony point zero is consistently asymptotically steady. Strength measure $\underline{\beta}$ can be computed utilizing [13], which are $\underline{\beta}_{S-IT2} = 0.7015$ for smoother control activity fuzzy framework and $\underline{\beta}_{A-IT2} = 0.4627$ for forceful control activity fuzzy framework. From this it may be indulged that smoother control activity fuzzy framework is stronger than forceful control activity fuzzy framework.

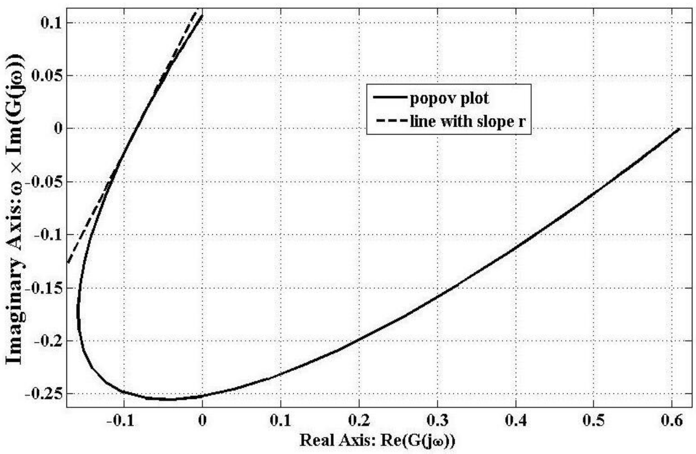


Fig.6 Popov plot of $G_{S-IT2}(s)$

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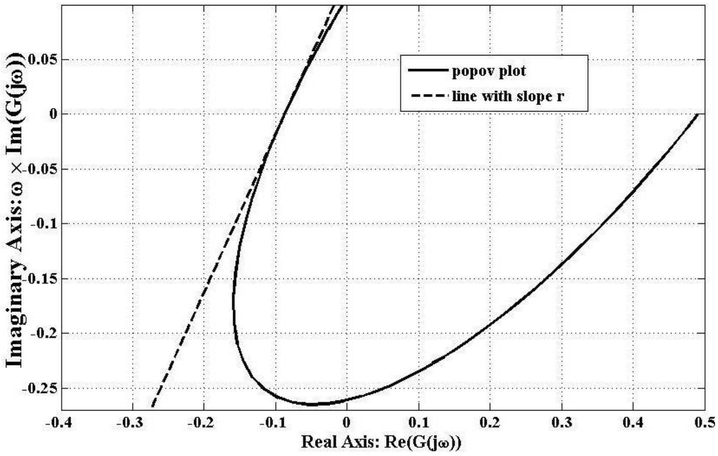


Fig.7 Popov plot of $G_{A-IT2}(s)$

## V. CONCLUSION

Forceful control bend is favoured for quick transient reaction, since it is delicate to commotion particularly around set point esteem. At relentless state, Controller which has a smooth control surface is conceivably more powerful against non-linearities and vulnerabilities. S interval type-2 fuzzy logic controller gives diverse reaction for various footprint of uncertainty parameters. Interval Type 2- fuzzy logic controller proportional integration and derivative beats the proportional–integral–derivative controller and also Type 1 Fuzzy PSO controller.

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