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Multi-Loop PID Controller Design for MIMO Processes Based On SIMC Fractional Order Filter

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Abstract- This paper presents a multiloop control for the different dimensional multivariable processes which are having the strong interrelation amid its variables. The objective of this discussion is to enhance the overall performance of the system by reducing the effects of interrelation of process variables. The prerequisite for design of multi loop control is to determine the best pair of controlled variables. In this paper the pair of variables is identified by using the relative gains of the process variables. Based on these, the pair of possible control loops is identified and their FOPDT models are approximated. Then to improve the servo operation (for set point changes in input) the PID controller parameters are calculated for these models using Simplified IMC tuning formulas. To minimize the effects of interrelations fractional order filter is used. With this combination, the overall objective of the control system is fulfilled i.e., tracking the set point and lessening the interaction. To show the effectiveness, the two examples are considered with different dimension, interaction and controller is designed. The results show that the SIMC algorithm improved the performance of the system.

Key words – Interrelations of variables, time delay, servo operation, Simplified IMC, fractional order filter, multi loop control.

I. INTRODUCTION

Most modern procedures are Multiple Input-Multiple Output (MIMO) frameworks and their control is hard to the point that the field still remains an attractive subject of research. The multifaceted nature is because of the phenomenon of the interrelations that exists amid the variables of the procedure so that each controlled variable can influence all the controlled factors. In this way, the primary target of the control plan for multivariable frameworks is to keep up its outputs at autonomous set-focuses within the sight of these interactions. Numerous methodologies have been produced for the control design in both state space and transfer function models. The Relative Gain Array (RGA) is employed in this proposal for determining the pair of control loops.

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In the frequency domain, the MIMO frameworks control strategies are characterized into three primary classes. The first one is multivariable controllers (full dimensional control), they involve intrinsic computations and a great deal of instrumentation to actualize [1, 2]. Thus, the uses of these are limited in industries.

The second one is decoupling strategies with diagonal controllers. Consequently, all tuning techniques revealed in the writing for Single Input-Single Output (SISO) frameworks can be connected autonomously for each control loop. The most important thing in usage of decoupler is it requires the exact mathematical model of the physical processes.

The third one is multiloop (decentralized) strategies. This control technique requires two stages. To begin with, the level of the connections in the multivariable procedure is assessed utilizing various RGA measures [3], the RNGA (Relative Normalized Gain Array) [4]. At that point, the satisfactory pair of control loop is picked. If the improper pair selected for intend of controller, will results the system completely unstable.

The target of choosing the best matching is to limit interrelation effect among the control loops. Also, the controller is intended for each circle utilizing numerous accessible tuning strategies, for example, the detuning techniques where every controller is determined to utilize the comparing component in the exchange grid overlooking the interrelation from different circles. The controllers are then detuned to take into record the cooperation until some endorsed farthest point. In the successive loop closing techniques, the loops are lock consistently. The end succession more often begins with the quickest circle. The dynamic relations of this circle are then considered at the end of the following loop, etc [2]. The multiloop (decentralized) controller structure techniques dependent on the IMC concept are considered.

The multiloop (decentralized) control is the control scheme which is popularly using in the industry due to its easiness to understand and to implement. Good control can be achieved in many cases and reduces the hardware required and cost.

The strength regarding the mathematical procedural errors in modelling and procedure and the decrease of the quantity of tuning parameters in the controller configuration are the fundamental points of interest exhibited by the IMC structure [5].

It is pertinent to take note of that the multiloop control is the most boundless in the real time processes because of its effectiveness to comprehend and to actualize.

Great control can be accomplished much of the time and the multifaceted nature with a low cost [6, 7].

Note that the previously mentioned control plan techniques for multivariable frameworks are kept to an exchange off between the feasible framework yields performance and the effect of interrelation level among the individual circles.

The paper is planned as structure of multivariable control scheme is explained in Section II, model approximation in Section III, Control design in Section IV and simulation studies in Section V. At the last the conclusions drawn is included.

II. STRUCTURE OF MULTIVARIABLE PROCESSES

A schematic representation of general multi loop (decentralized) control configuration of multivariable processes are shown in Fig.1. In this proposed case, the filter is used for rejection of loop interrelations and diagonal control ($G_c(s)$) is for tracking the servo operation. The elements present in proposed control system are filter $f_i(s)$, decentralized controller $G_c(s)$, and process $G_p(s)$.

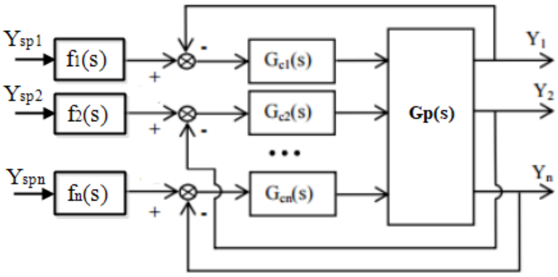

Fig.1.Structure of proposed multiloop (decentralized) control system

The conventional representation of the transfer function matrix of the $n \times n$ process is:

$$G_p(s) = \begin{bmatrix} g_{p11}(s) & g_{p12}(s) & L & g_{p1n}(s) \\ g_{p21}(s) & g_{p22}(s) & L & g_{p2n}(s) \\ M & M & O & M \\ g_{pn1}(s) & g_{pn2}(s) & L & g_{pnn}(s) \end{bmatrix} \quad (1)$$

Where, the process $g_{pij}(s)$ is considered as first order process with delay time (FOPDT), i.e.,

$$g_{pij}(s) = \frac{K}{\tau s + 1} e^{-\theta s} \quad (2)$$

The corresponding structure of decentralized controller is of the form,

$$G_c(s) = \begin{bmatrix} g_{c11}(s) & . & . \\ . & O & . \\ . & . & g_{cnn}(s) \end{bmatrix} \quad (3)$$

For comfort, it is accepted that the quantity of controlled factors in multivariable procedures is equivalent to the number of manipulated factors. This permits matching of a single controlled variable with a solitary controlled variable through an analysis controller. For matching of factors, two techniques are utilized in particular RGA and RNGA. These two are talked about in section III.

III. MODEL APPROXIMATION USING RELATIVE GAINS

A. *Relative Gain Array(RGA)*

The RGA for $n \times n$ systems is,

$$\Lambda = G_p(0) \otimes G_p^{-T}(0) \quad (4)$$

B. Relative Normalized Gain Array (RNGA)

By using the two parameters of the process like Average Residence Time (ART) and speed of response, the normalized gain ($K_{N,ij}$) of the process can be defined as:

$$K_{N,ij} = \frac{g_{ij}(0)}{\tau_{ar,ij}} \quad (5)$$

In general, $K_{N,ij}$ represents the fastness of the system response in controlled variable with respect to change in manipulated variable. Mathematically, the ART $(\tau_{ar,ij})$ can be defined as:

$$\tau_{ar,ij} = \tau_{ij} + \theta_{ij} \quad (6)$$

Then the normalized gain is:

$$K_{N,ij} = \frac{g_{ij}(0)}{\tau_{ar,ij}} = \frac{k_{ij}}{\tau_{ij} + \theta_{ij}} \quad (7)$$

Therefore, the RNGA (ϕ) can be expressed as:

$$\phi = \left[\phi_{ij}\right]_{n \times n} = K_N \otimes K_N^{-T} \quad (8)$$

C. Model approximation

To estimate/approximate the equivalent mathematical model of the given process, we first define the relative ART (γ_{ij}), i.e.,

$$\gamma_{ij} = \frac{\hat{\sigma}_{ij}}{\sigma_{ij}} = \frac{\phi_{ij}}{\Lambda_{ij}} \quad (9)$$

Similarly, representing it is in the array form is called the RARTA which will be expressed as:

$$\text{RARTA}(\Gamma) = \phi \odot \Lambda \quad (10)$$

Where, '$\odot$' signifies the element by element division. From an Eqn. (9), it is simplified as:

$$\hat{\sigma}_{ij} = \gamma_{ij}\sigma_{ij} \quad (11)$$

$$\hat{\sigma}_{ij} = \hat{\tau}_{ij} + \hat{\theta}_{ij} \quad (12)$$

Using RGA and RARTA, it is likely to write the estimated FOPDT frame as:

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$$\hat{g}_{ij}(s)=\frac{k_{ij}}{\Lambda_{ij}}\frac{1}{\gamma_{ij}\tau_{ij}s+1}e^{-\gamma_{ij}\theta_{ij}s} \quad (13)$$

IV. CONTROL SYSTEM DESIGN

This section includes the two steps to intend the overall controller in order to enhance both servo performance and interaction minimization.

A. Fractional Order set point filter

The fractional order filter is utilized to upgrade the presentation of the framework under successive set-point changes. The filter is designed as [8]:

$$f_i(s)=\frac{1}{1+\tau_{ci}s^{\alpha_i+1}}, \qquad i=1,2,.....n \quad (14)$$

In this examination, the τ_{ci} and α_i qualities are chosen to achieve the comparative unique execution of the closed loop model for each loop as that of proposed. These parameters are chosen as little enough to decrease the result of the relations on loops and to ensure the steadiness of the framework.

B. Tuning of controller Using SIMC method

The controller being used to attain the expected performance for the system of FOPDT process is given in the form of as given in equation,

$$g_{c,ii}(s)=k_{c,ii}\left(1+\frac{1}{\tau_{Ii}s}\right) \quad (15)$$

The resulting PI controller parameters are given as [9]:

$$K_{c,ii}=\frac{1}{K}\left(\frac{\tau_{ii}}{\tau_{c,i}+\theta_{d,ii}}\right) \quad (16)$$

$$\tau_{1i}=\min(\tau_{ii},\ 4(\tau_{c,i}+\theta_{d,ii})) \quad (17)$$

In SIMC structure, the tuning parameter $\tau_{c,i}$ is proposed to be taken as time delay $\theta_{d,ii}$ so as to get the nonzero controller increase and it likewise gives the ideal tradeoff between quick reaction and robustness.

The following procedure includes the complete development of controller for multi loop (decentralized) control:

i) The interaction of the procedures must be measured first be measured. This document uses RGA and RNGA configuration guidelines to measure the relationship amid the variables of system.

ii) Based on the results of step 1, the matching of info and pair of loops are framed and the relating procedure model is utilized to plan the controller.

iii) In the presentation of multi variable procedures, time deferral assumes a significant point, it is considered in this paper and RNGA based ETF setup is utilized to repay the time delay.

iv) Finally, the controller is intended for the procedure model utilizing the SIMC rule and execution of the methodology is assessed. For interaction minimization, the filter is design as in Eqn. (14).

V. SIMULATION RESULTS AND DISCUSSIONS

***Example 1*:** To delineate the controller plan technique proposed here, we consider the model given by:

$$G(s)=\begin{bmatrix}\frac{3.5e^{-s}}{s} & \frac{-e^{-5s}}{2s+1}\\ \frac{2e^{-7s}}{1.5s+1} & \frac{-e^{-5s}}{3.2s+1}\end{bmatrix} \quad (18)$$

The RGA of the model is:

$$\lambda=\begin{bmatrix}2.333 & -1.333\\ -1.333 & 2.333\end{bmatrix}$$

Relative Normalize Gain Array (RNGA) is:

$$\phi=\begin{bmatrix}0.8647 & 0.1353\\ 0.1353 & 0.8647\end{bmatrix}$$

From these two approaches it is observed that the pair (u_1- y_1) and (u_2- y_2) is having enough amount of interaction to control the corresponding outputs. Thus, the diagonal process transfer function models are considered for intend of controller are:

$$g_{p,11}(s)=\frac{3.5e^{-s}}{s} \qquad g_{p,22}(s)=\frac{-e^{-5s}}{3.2s+1}$$

Based on these two process models, the diagonal decentralised (multi loop) controllers are intended individually (g_{c11} and g_{c22}) using SIMC tuning method. The controller for proposed methods and IMC FOPID controllers are obtained as:

$$G_{c,Proposed}(s)=\begin{bmatrix}0.142 & 0\\ 0 & \left(-0.32+\frac{1}{3.2s}\right)\end{bmatrix}$$

The set point/reference side filter for lessening the effect of interrelation of variables is obtained by Eqn. (14) as:

$$f_{11}(s)=\frac{1}{1+2s^{1.3}}(1+0.1s), \qquad f_{22}(s)=\frac{1}{1+2s^{1.3}}(1+s)$$

The simulation outcome of this approach with related approaches is depicted in Figs. 2 and 3 individually. The disturbance also included in the process input as:

$$G_d(s)=\begin{bmatrix}\frac{-4.5}{2s+1} & \frac{-4.5}{2s+1}\end{bmatrix}$$

The output results of proposed control of Fig. 5 and Fig. 6 demonstrate that the procedure outputs meet the ideal dynamical conduct determined by the reference model for each loop with worthy control exertion. The impact of connections is clear in both transient and unfaltering conditions of the two reactions as can be found in the RGA ramework whose components are more prominent than one.

So as to demonstrate the robust stability of the projected multiloop controller regarding the aggravations, the vector unsettling influence of is presented at the procedure output at t = 0 for the primary output and at t = 100 for the second output with 0.1step for each info unsettling influence and the acquired outcomes. The individual control sign has likewise appeared in Figs. 4 and 5 independently. The smoothness of this is improved in the proposed methodology. In this manner, improves the existence time of control factors utilized in the control loop. For correlation reason, the IMC based FOPID is utilized in this paper.

From these results, it is seen that the right now proposed strategy improves the general execution by diminishing the impact of interrelations of the parameters.

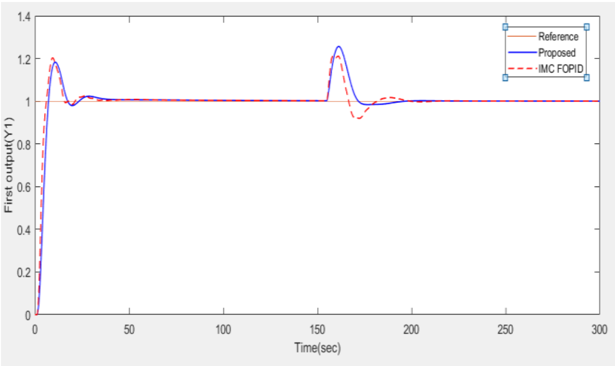

Fig. 2: Closed loop response of first output (Y_1) of example 1

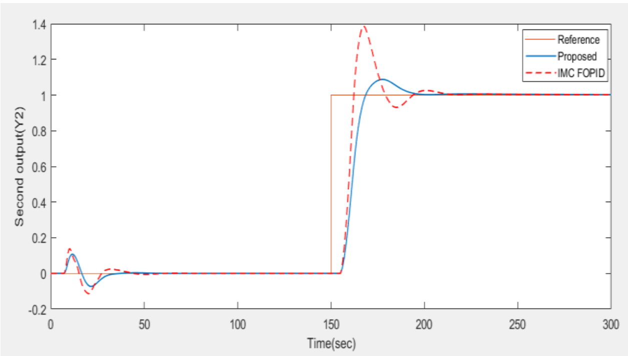

Fig. 3: Closed loop response of second output (Y_2) of example 1

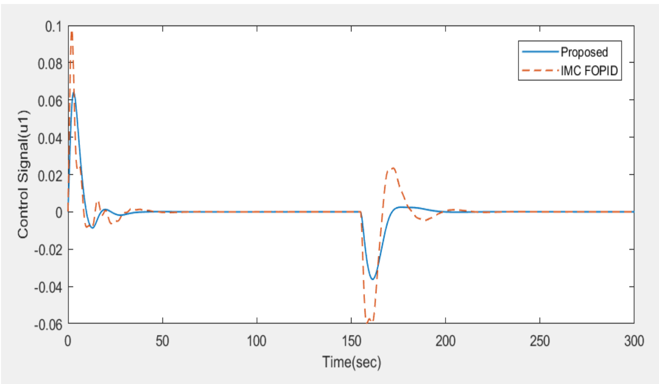

Fig. 4: Control signal (u_1) of example 1

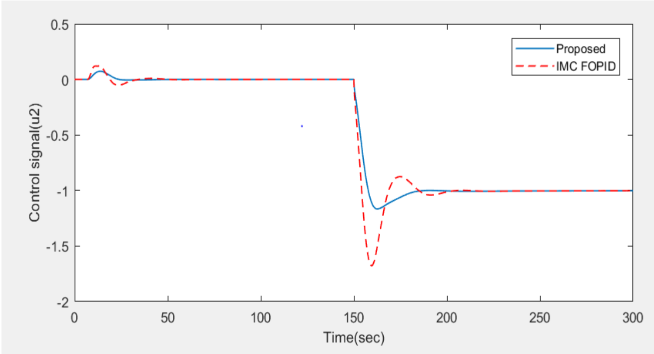

Fig. 5: Control signal (u_2) of example 1

Example 2: To validate the efficacy of current algorithm, the second process is considered as Ogunnaike et al [10] distillation column TFM model is considered in this section. The model of this process is:

$$G_p(s)=\begin{bmatrix} \frac{0.66}{6.7s+1}e^{-2.6s} & \frac{-0.61}{8.4s+1}e^{-3.5s} & \frac{-0.0049}{9.06s+1}e^{-6s} \\ \frac{1.11}{3.25s+1}e^{-6.5s} & \frac{-2.36}{5s+1}e^{-3s} & \frac{-0.01}{7.09s+1}e^{-1.2s} \\ \frac{-34.68}{8.15s+1}e^{-9.2s} & \frac{46.2}{10.9s+1}e^{-9.4s} & \frac{0.87(11.61s+1)}{(3.89s+1)(18.8s+1)}e^{-s} \end{bmatrix} \quad (23)$$

The computed values of RGA (Λ) and RNGA (ϕ) of the OR column are:

$$\Lambda=\begin{bmatrix} 2.0084 & -0.7220 & -0.2864 \\ -0.6460 & 1.8246 & -0.1786 \\ -0.3624 & -0.1026 & 1.4650 \end{bmatrix}$$

$$\text{RNGA}(\phi)=\begin{bmatrix} 1.5504 & -0.4001 & -0.1504 \\ -0.3775 & 1.4557 & -0.0782 \\ -0.1730 & -0.0556 & 1.2286 \end{bmatrix}$$

The RGA (2.0084) and RNGA (1.5504) prescribes that the pair of circles present in the diagonal for the plan of multi circle/decentralized PI control. The equal model parameters and relating ETF is determined as:

$$g_{p11}(s)=\frac{0.3286}{5.1723s+1}e^{-2.0072s}, \quad g_{p22}(s)=\frac{-1.2935}{3.9891s+1}e^{-2.3934s}$$

$$g_{p33}(s)=\frac{0.5939}{8.1976s+1}e^{-0.7548s}$$

Based on these two process models, the diagonal decentralised (multi loop) controllers are intended individually (g_{c11} and g_{c22}) using SIMC tuning method. The filters ($f_{ii}(s)$) also calculated according the Eqn. (14). The controller parameters for first loop are k_c=0.1192, k_i=0.1593, for second loop k_c=-0.055, k_i=-0.0455 and for third loop are k_c=2.34, k_i=0.3692. For comparison purpose the IMC based fractional order filter is used.

The set point/reference side filter for lessening the effect of interrelation of variables is obtained by Eqn. (14) as:

$$f_{11}(s)=\frac{1}{1+9s^{1.06}}(1+4s)$$

$$f_{22}(s) = \frac{1}{1+6s^{1.08}}(1+2s)$$

$$f_{33}(s) = \frac{1}{1+0.4s^{1.06}}(1+0.1s)$$

Unit step changes in set-point inputs are sequentially made in the individual loops at moments t = 0, t = 200 and t = 400. The simulation results of Figs. 6, 7and 8 shows the step responses. The control effort for this response is shown in Figs 9, 10 and 11 respectively.

The proposed method has shows the improved the performance for first, second and third output compared to the other previous method considered in this paper. For the first output the input is applied at t=0 sec, second output at t=200 and third output at t=400 sec. The response of projected approach has fewer oscillations before settling to the final value as compared to the IMC FOPID.

Further, the control signals also compared with related approach, but the control signal of present method is smoother as compared with other approaches. At the last, it can be observed that the overall performance of system is improved with the proposed method.

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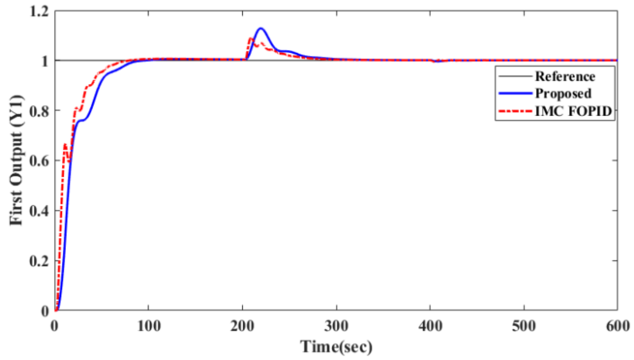

Fig. 6: Closed loop response of first output (Y_1) of example 2

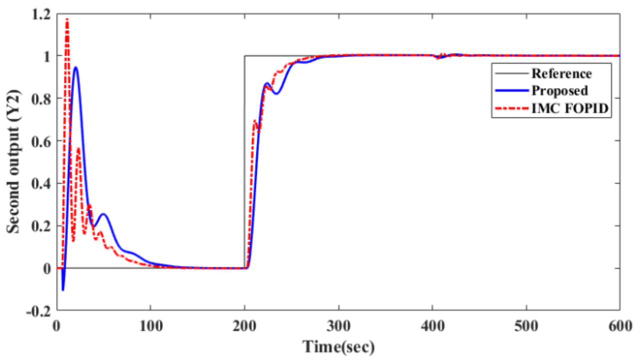

Fig. 7: Closed loop response of Second output (Y_2) of example 2

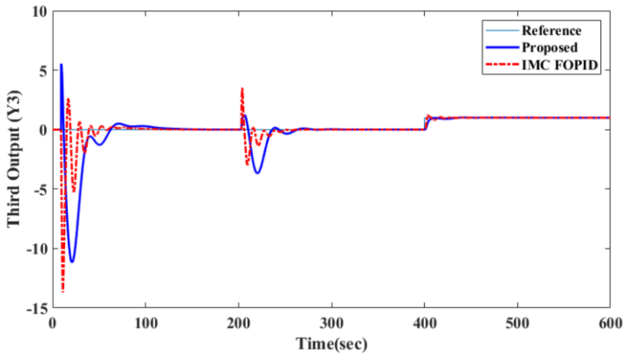

Fig. 8: Closed loop response of third output (Y_3) of example 2

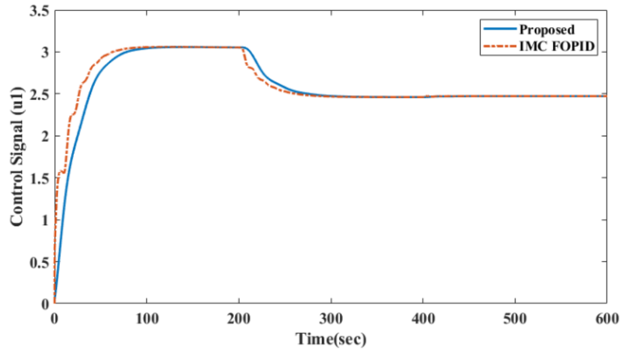

Fig. 9: Control signal (u_1) of example 2

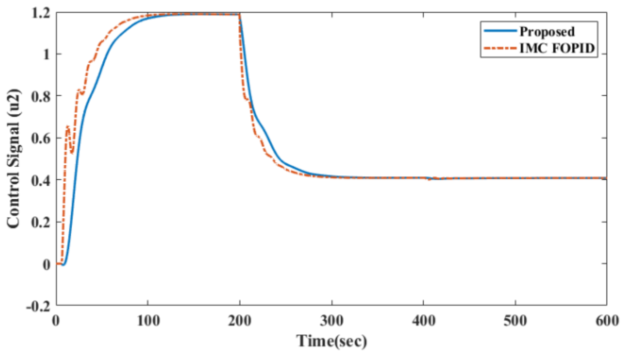

Fig. 10: Control signal (u_2) of example 2

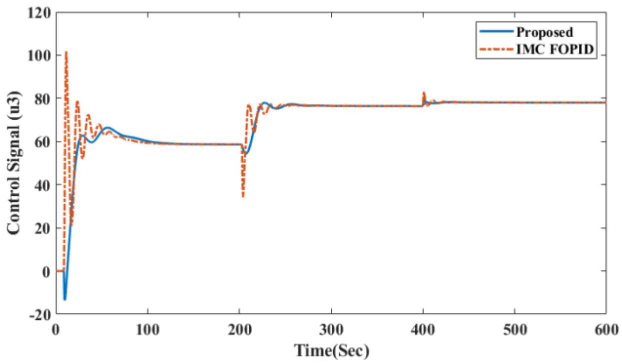

Fig. 11: Control signal (u_3) of example 2

VI. CONCLUSIONS

This paper describes the multiloop (decentralized) control intend for the multivariable processes which are having the strong effect of interrelation between the process variables. The interrelations amid the variables are measured using RGA and RNGA. Based on the outcome, the control configuration of control loops has been formed. The corresponding models of the processes have been derived using the RARTA and RGA approaches. For the equivalent model the controller is designed using SIMC and set point filters are also added in the loop. Thus, the resultant system improved the performance of the system and robustness also. The results of simulation studies shown that proposed method have the better response than the method using for comparison. The smoothness of control action also improved.

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