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Optimal Control of Quadruple Tank System Using Genetic Algorithm

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Abstract: Multivariable framework includes in excess of one control loop, these loops communicate with each other, in such a way, to the point that solitary information influences its own output as well as influences different process outputs. The quadruple tank system is basically a water level control issue and the best research facility case to break down the nonlinearities and interactions in process enterprises. Traditional controller techniques, similar to (PI) with (IMC), don't advance the framework. Consequently the optimization techniques, for example, Bacteria Foraging optimization(BFO), Particle swarm Optimization(PSO),and the proposed strategy Genetic Algorithm(G.A),are used to enhance the dynamic and steady state error execution of the framework to deal with the nonlinearities and interactions. Mat lab recreations are utilized to appear the best execution and reasonable comparison between all controllers' strategies.

Keywords: Quadruple tank,Decoupler,Relative Gain Array,(PI-MIC),(BFO),(PSO),(G.A) Matlab

1. Introduction

Modern control issues are generally non-linear in nature and have various control factors. The frameworks associated with such modern process indicate huge vulnerabilities, non-minimum phase behavior and a considerable measure of cooperation [1]. Multivariable framework includes in excess of one control loop, these loops interface with each other, in such a way, to the point that solitary information influences its own particular output as well as influences different process outputs. [2,3]. The quadruple tank has gotten an extraordinary consideration since it presents intriguing properties in both control training and research [4]. The quadruple tank framework is broadly utilized as a part of envisioning the dynamic connections and nonlinearities showed in the activity of intensity plants, compound businesses and biotechnological fields. The control of such connecting multivariable procedures is of extraordinary enthusiasm for process enterprises, fluid level frameworks are frequently excessively basic, making it impossible to delineate different process progression, then again, the quadruple tank system(QTS) breaks such negative perspectives of fluid level frameworks without including extra complex contraption [5]. (QTS) is a very nonlinear framework which has been utilized to test distinctive MIMO controllers intended for this procedure. For instance, a decentralized proportional integral (PI) controller [4, 6], a decentralized PI controller with sliding mode highlights [7], a decoupled proportional integral and derivative (PID) controller [16], an internal model controller [8], a model predictive controller [9,10], a quantitative feedback controller [11],fuzzy logic controller[12] , neural system control[13] and a H∞ controller [14] were proposed for the control of the(QTS). These control plans were composed utilizing the linearized model of the (QTS) around various working levels. Henceforth, these controllers can't guarantee great exhibitions of the controlled framework over the whole working scope of the procedure on account of the inalienable nonlinearities in it. With a specific end goal to accomplish great exhibitions over the entire working scope of the (QTS), other control strategies were accounted for in the literature. Nonlinear model predictive controllers where outlined in [15, 16] for the process. In [17], a sliding mode controller was composed and actualized on the framework. However, a singularity may encounter when utilizing this controller that as well when one of the four tanks is unfilled. Consequently, the proposed controller can't be executed in such case. In [18], a linear decentralized PI controller was composed in light of the approximated nonlinear model of the procedure over a chose scope of activity of the process. The recreation

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comes about demonstrate a good following conduct over the chose working reach. Then again, the work in [19] managed the outline of a pick-up planning PI controller for the process; the pick-up gain configuration is finished by the working input voltages.

In this paper, a Genetic Algorithm (G.A) controller comprising of a proportional plus integral control are designed and actualized to control the fluid levels in the (QTS) over the entire scope of activity of the framework. Aside from this, an integral mode is incorporated into the control plan, keeping in mind the end goal to accomplish great following execution (zero steady state error). The usage comes about are displayed to demonstrate the adequacy of the proposed control conspire contrasted with others control techniques. In this work a (QTS) will be demonstrated utilizing the linear model after a few suspicions. The recreation results will be displayed to dissect the execution of (G.A) strategy. The remainder of the paper is organized as follows: Section 2 presents the dynamic model of the (QTS). Section 3 explains the controller's types for (QTS), classical and intelligent. Section 4 presents the results and discussion, with a comparison between the proposed and others controllers based on simulation results. Finally, Section 5 contains the main conclusions.

2- QTS MODELING

The (QTS) as appeared in Figure.1 is a framework with two inputs sources, the voltages of the pumps speed, which can be controlled to control the two outputs (tank levels). The framework displays communicating multivariable elements on the grounds that every one of the pumps influences both of the outputs. A scientific model in light of physical information together with its linearization around a working point is determined in[4,12,20,21,22,23,24,25].

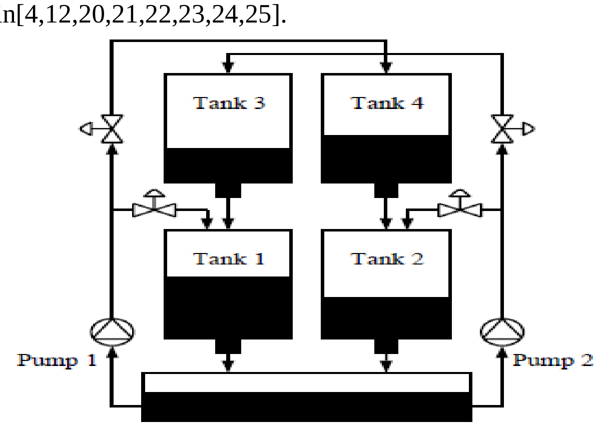


Figure.1 shows the schematic-diagram of QTS.

Displaying of the tank is finished by utilizing the mass adjust condition and Bernoulli's law. Mass adjust condition expresses that:-

[Rate of accumulation] = [Rate of in-flow]-[Rate of outflow] (1)

Where, the input mass flow-rate (qini),is given as:-

$$\begin{aligned} qin1 &= \gamma 1K1V1 \\ qin2 &= \gamma 2K2V2 \\ qin3 &= K2V2(1-\gamma 2) \\ qin4 &= K1V1(1-\gamma 1) \end{aligned} \tag{2}$$

Where (K1,K2) are the pump constants and $(\gamma 1, \gamma 2)$ are value ratio of valve positions and(V1,V2) are input voltages to pump.

And the output mass flow-rate (qouti) is given as:-

$$qouti = ai\sqrt{2ghi}$$

The final equations for i=1,2,3,4 are:-

$$\begin{aligned} \frac{dh1}{dt} &= \frac{\gamma 1K1V1}{A1} + \frac{a3\sqrt{2gh3}}{A1} - \frac{a1\sqrt{2gh1}}{A1} \\ \frac{dh2}{dt} &= \frac{\gamma 2K2V2}{A2} + \frac{a4\sqrt{2gh4}}{A2} - \frac{a2\sqrt{2gh2}}{A2} \\ \frac{dh3}{dt} &= \frac{(1-\gamma 2)K2V2}{A3} - \frac{a3\sqrt{2gh3}}{A3} \\ \frac{dh4}{dt} &= \frac{(1-\gamma 1)K1V1}{A4} - \frac{a4\sqrt{2gh4}}{A4} \end{aligned} \tag{3}$$

Where (ai) cross sectional area of the outlet pipes and (g) acceleration due to gravity.

The non-linear relationship in the equ.3 is because of the square root term show in those conditions which influences the controller to outline troublesome. To beat the trouble, the linearization is required. The equ.3 is tackled utilizing Taylor arrangement taken after by Jacobian matrix change to acquire a state space type of the QTS[20,22,25].The state-space conditions are:-

$$A = \begin{vmatrix} -\frac{1}{T1} & 0 & \frac{A3}{A1T3} & 0 \\ 0 & -\frac{1}{T2} & 0 & \frac{A4}{A2T4} \\ 0 & 0 & -\frac{1}{T3} & 0 \\ 0 & 0 & 0 & -\frac{1}{T4} \end{vmatrix} \quad (4)$$

$$B = \begin{vmatrix} \frac{\gamma 1K1}{A1} & 0 \\ 0 & \frac{\gamma 1K1}{A1} \\ 0 & \frac{(1-\gamma 2)K2}{A3} \\ \frac{(1-\gamma 1)K1}{A4} & 0 \end{vmatrix} \quad (5)$$

$$C = \begin{vmatrix} Kc & 0 & 0 & 0 \\ 0 & Kc & 0 & 0 \end{vmatrix} \quad (6)$$

To determine the transfer function, using the formula:-

$$G(s) = C(SI - A)^{-1}B + D$$

$$G(s) = \begin{vmatrix} \frac{\gamma 1C1}{(1+T1s)} & \frac{(1-\gamma 2)C1}{(1+T1s)(1+T3s)} \\ \frac{(1-\gamma 1)C2}{(1+T2s)(1+T4s)} & \frac{\gamma 2C2}{(1+T2s)} \end{vmatrix} = \begin{vmatrix} G11(s) & G12(s) \\ G21(s) & G22(s) \end{vmatrix} \quad (7)$$

Where C1 and C2 are defined as:-

$$C1 = \frac{T1K1Tc}{A1}$$
$$C2 = \frac{T2K2Kc}{A2} \quad (8)$$

A minimum phase framework does not have zeros or poles in the right portion of the s-plane. According[26], the scope of stage angle in such framework is least. In the (QTS) minimum phase process, the entirety of the valve constants is more than one and less than two . As indicated by [4], for this situation the stream of fluid to bring down tanks is more noteworthy than the stream in the upper tanks.

In this paper, it picked the minimum phase framework [22], and in the wake of substituting the parameters of the tank framework, we get:-

$$G(s) = \begin{vmatrix} \frac{11.89}{1+121.4s} & \frac{6.875}{(1+121.4s)(1+3.967s)} \\ \frac{6.738}{(1+84.73s)(1+3.109s)} & \frac{11.53}{(1+84.73s)} \end{vmatrix} \quad (9)$$

2.1- RELATIVE GAIN ARRAY (RGA)

If that decentralized control structure is picked as a (MIMO) controller, a proper matching of input and output is required. For this situation of a (mxm) plant model, there is m! Distinctive pairings. Incidentally, physical elucidation of framework gives thought regarding which pairing is helpful or which one isn't. Relative Gain Array (RGA) is a strategy that can be utilized to propose pairings through a known amount. RGA is characterized as a matrix [27]:

$$\Delta = G(0) * G^{-T}(0) \quad (10)$$

When the diagonal of (Δ) is negative then controlling the framework is especially troublesome. A matching with $0.61 < \lambda < 1.50$ in principle diagonal components as a rule gives great execution [27]. The RGA of the quadruple framework is given as:

$$\Delta = \begin{vmatrix} \lambda & 1-\lambda \\ 1-\lambda & \lambda \end{vmatrix} \quad (11)$$

$$\lambda = \frac{\gamma 1\gamma 2}{\gamma 1 + \lambda 2 - 1} \quad (12)$$

Here, $(\gamma 1 = \gamma 2 = 0.6311)$, the output (y1) is controlled by input(u1) and (y2) is controlled by(u2).

2.2 DECOUPLER

Since ,equ(9),represent (MIMO) framework, it is issue for controller plan, it is legitimate to change over to(SISO) framework, this should be possible by utilizing decoupler technique, This sort of control stays away from the impacts of loop interactions completely. The decoupler separates a MIMO procedure into a couple of free single-loop subsystems, as per perfect decoupling system [28].The decoupler transfer functions matrix is:-:-

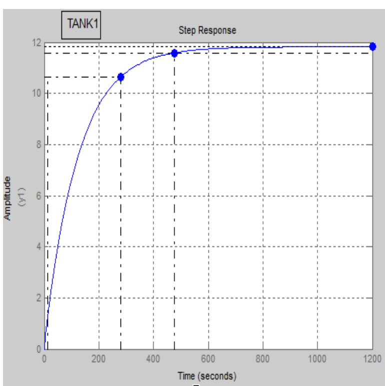
$$D(s) = \begin{vmatrix} D11(s) & D12(s) \\ D21(s) & D22(s) \end{vmatrix} \quad (13)$$

Where the diagonal elements, D11 = D22 = 1 (ideal decoupler case), and off diagonal elements are:-

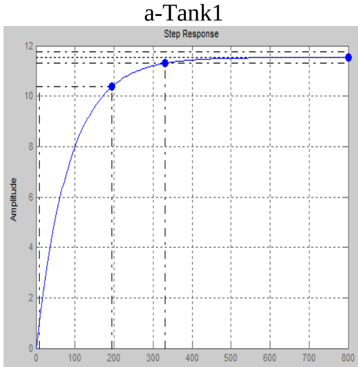
$$D12(s) = \frac{-G12(s)}{G22(s)}$$
$$D21(s) = -\frac{G21(s)}{G11(s)} \quad (14)$$

3. CONTROLLERS TYPES

In this paper, numerous controllers' types are studies and comparison between them are organized by transient reaction outline details (rise-time, settling-time, greatest overshoot and steady state error). The correlation between proposed strategy (G.A) and the established (PI) with Internal Model Control method (IMC), Bacteria Foraging Optimization Algorithm (BFO), Particle Swarm Optimization Algorithm (PSO) are exhibited in following section.figure.2 demonstrates the level transient reaction of (QTS) without controller for tank1 and tank2.



a-Tank1



b-Tank2

Figure 2. shows the output transient response of ,a-Tank1, b-Tank2 without controller

3.1 PI CONTROLLER TUNING BY USING INTERNAL MODE TECHNIQUE(PI-IMC)

Subsequently this plan can be utilized to create PI structure, with the goal that the execution of the control framework can be made strides. The Internal Model Control (IMC) is a control framework configuration in view of the Q-parameterization idea [29]. It has been a famous controlling procedure in the process control enterprises particularly in the tuning of single loop PI controllers. The tuning equation for IMC strategy is given as [22]:

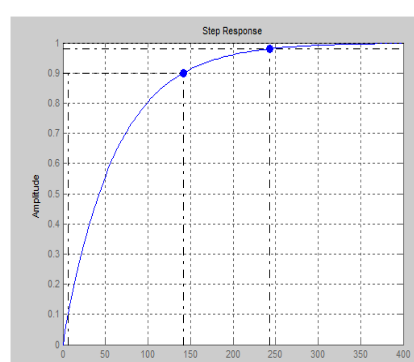
$$Kp = \frac{1}{K}\frac{\tau}{\tau c}$$
$$Ti = \tau \quad (15)$$
$$Ki = \frac{Kp}{Ti}$$

Where, (Kp) is the proportional gain and(Ki) is the Integral gain, (K) is the process gain, (Ti) is the integral time, (τ) is the process time constant and (τc) is the desired time constant. By substituting the parameters, we get the values, as shown in Table.1

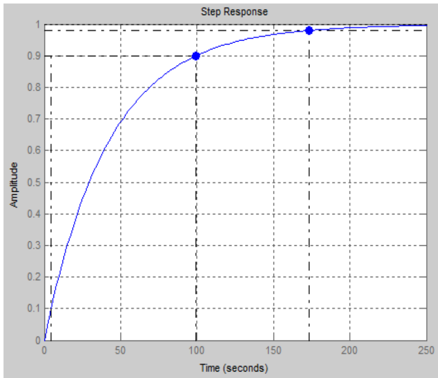
Table.1 shows PI-IMC tuning parameters [22]

Method	Tank1	Tank1	Tank2	Tank2
PI-IMC	Kp=0.1682	Ki=0.00138	Kp=0.1734	Ki=0.002004

Fig (3) shows transient response for both tanks using (PI-IMC) method, it is clear the improvement in steady-state error which equal to zero, also in the speed response But, still the desired response not meets (minimum rise and settling time).



a-Tank1



b-Tank2

Figure 3. shows the transient response of a-Tank1, b-Tank2 using (PI-IMC)

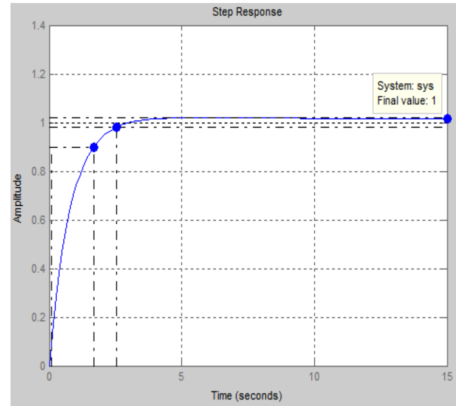
3.2 BACTERIA FORAGING OPTIMIZATION ALGORITHM (BFO.A)

The Bacteria Foraging is a transformative calculation which gauges cost work after every iterative advance of the program as the program execution continues and prompts continuously better fitness (less cost work). The parameters to be enhanced speak to facilitates (position) of the microscopic organisms. The parameters are discretized in the attractive range, each arrangement of these discrete qualities speak to a point in the space facilitates [30]. After numerous iterations, poor searching procedures are destroyed or shaped into great ones. This action of rummaging drove the analysts to utilize it as advancement process. The tuning parameters acquired utilizing this method is appeared in Table.2

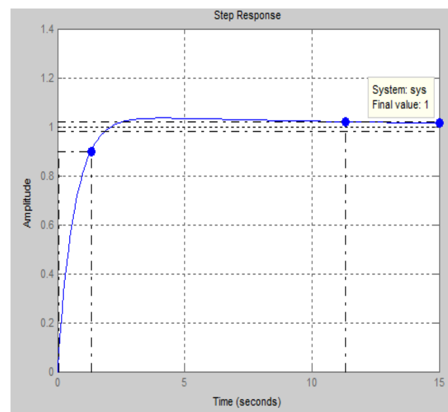
Table.2 shows BFO tuning parameters [22]

Method	Tank1	Tank1	Tank2	Tank2
BFO	Kp=13.213	Ki=0.5007	Kp=11.503	Ki=0.9485

Fig (4) shows transient response for both tanks using (BFO.A) method, it is clear the improvement in steady-state error which equal to zero ,also in the speed response, the settling time is very much reduced when compared to the conventional PI-IMC controller.



a-Tank1



b-Tank2

Figure 4. shows the transient response of a-Tank1, b-Tank2 using (BFO)

3.3- PARTICLE SWARM OPTIMIZATION ALGORITHM(PSO.A)

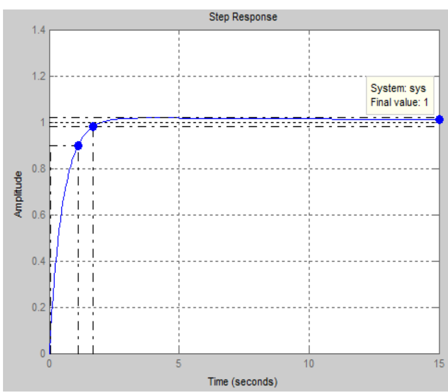
Particle swarm improvement is a heuristic worldwide streamlining technique and furthermore an enhancement calculation, which depends on swarm knowledge. It originates from the examination on the flying creature and fish run development conduct. The calculation is generally utilized and quickly created for its simple execution and couple of particles required to be tuned [31]. The particles are introduced and afterward the present fitness esteem is contrasted and the neighborhood best, if the present esteem is more prominent than the nearby best, it is supplanted with the neighborhood best. Correspondingly, the nearby best is contrasted and the worldwide best and the qualities are refreshed. The cycle proceeds until the point when the objective is come to. Integral Square Error (ISE), Integral Absolute Error

(IAE), Integral Time Square Error (ITSE), Integral Time Absolute Error (ITAE) is utilized as target capacities for PSO calculation. The best qualities are gotten from the calculation for ITAE criteria as goal function [22]. The tuning parameters got utilizing this error criteria (ITAE) is appeared in Table.3.

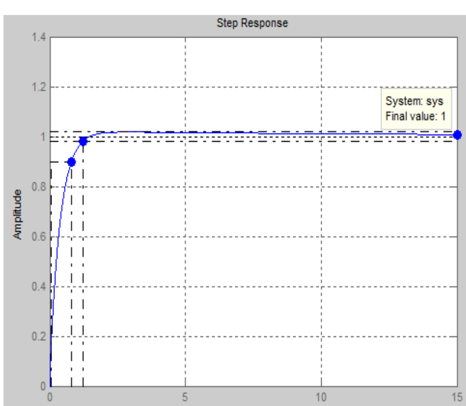
Table.3 shows PSO tuning parameters [22]

Method	Tank1	Tank1	Tank2	Tank2
PSO	Kp=20	Ki=0.9752	Kp=20	Ki=1.3624

Fig (5) shows transient response for both tanks using (BFO.A) method, It is seen that the PSO technique produces an optimal response by improving the dynamic performances in terms of rise time and settling time.



a-Tank1



b-Tank2

Figure 5. shows the transient response of a-Tank1, b-Tank2 using (BFO)

3.4- THE PROPOSED METHOD GENETIC ALGORITHM(G.A)

A standout amongst the most widely recognized developmental calculations is the (G.A). It depends on the component of regular choice. They take after the standard cycle ventures as developmental calculations. They utilize double or drifting qualities to speak to outline factors with settled length. At every emphasis, they utilize sets of two qualities with high fitness to produce new qualities by hybrid and change. The following populace is chosen in parent and youngsters qualities as indicated by wellness [32].

GAs give an elective strategies to taking care of issues and, specifically applications, they outflank other customary techniques. Particularly in genuine issues that include finding ideal parameters, GAs can conquer systematic challenges of customary techniques.

GAs was presented as a computational similarity of versatile frameworks. They are demonstrated freely on the standards of the development by means of normal determination, utilizing a population of individuals that experience choice within the sight of variety actuating administrators, for example, mutation and recombination (hybrid). A fitness work is utilized to assess individuals, and reproductive achievement shifts with fitness. The calculation can be condensed in the accompanying advances [33]:

1-Randomly produce an underlying population.

2. Calculate the fitness for every person in the present population.

3. Select a specific number of individuals that scored preferred execution over others as indicated by a predetermined choice mechanism.

4. Produce another population from the chose individuals applying hereditary administrators, for example, crossover or mutation.

5. Repeat from stage 2 until the point that an end model is checked.

The assignment of catching a controlled framework execution and restoring a one of a kind esteem portraying the nature of an answer was a standout amongst the most troublesome of this work. A few lists are considered with various purposes. In this paper and for good examination between the come about by utilizing (G.A) and others techniques, identified with [22], the error criteria (ITAE) can be picked as same in [22]. In a first arrangement of runs, a fixed number of generations were picked as end measure. The GA had a constrained measure of generation to advance an answer. In a second run, the end measure was set by an objective ITAE incentive to be reached. A most extreme number of generations, 80, are set on the target solution that the objective arrangement can't be found. In that case the search fails. The ITAE list gives a sign of the nature of the arrangement. The assessment time is the measure of time that the arrangements have been simulated. Since the time is adaptive on the grounds that better arrangements require less time to be assessed, when the inquiry don't create great results, it likewise takes additional time.

The optimization is accomplished in emphases frame called generations, and makes another arrangement of chromosomes at every generation through crossover and mutation, where the best chromosomes are permitted to the generation to come. In this work GA parameters are picked by the experimentation strategy as takes after:

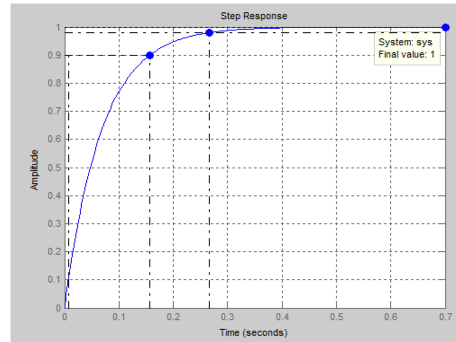
The size of the population=300, the maximum number of generations=120, It is for a termination criteria. The Crossover rate= 0.5 and Mutation rate=0.02, while the start points for (Kp) and (Ki) are chosen,(0.1682),(0.003) for tank1 respectively and(0.1734),(0.002),for tank2.

The tuning parameters obtained using (G.A) is shown in Table.4

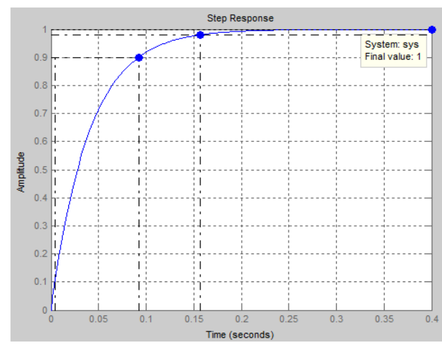
Table.4 shows G.A tuning parameters

Method	Tank1	Tank1	Tank2	Tank2
G.A	Kp=150	Ki=0.82	Kp=184	Ki=1.13

Fig(6) shows transient response for both tanks using (G.A) method, It is seen that the G.A technique produces an optimal response by improving the dynamic performances in terms of rise time and settling time and it gives very small values compared with others methods.



a-Tank1



b-Tank2

Figure 6. shows the transient response of a-Tank1, b-Tank2 using (G.A)

4. DISCUSSION

For the purpose to comparison between the performances of all controllers[22]and(G.A), it is necessary to simulate the transient responses for the tank1and tank2 level, this done after decoupling the loops to prevent the interactions.Table.5 shows the dynamic and steady-state performance according to rise and settling time.(PI-IMC),shows small improvements, for reducing these times relative to original system without controller, where(Tr=267sec)and(Ts=475sec),but it can be seen the increase in improvement, when using soft-computing techniques(BFO,PSO,G.A). (G.A), shows a better response (Tr=0.0878sec) and (Ts=0.157sec), but GA requires 32.156 seconds computational time to tune the PI controller.

Table.5 shows performance comparison between all controllers

process	Tuning-method	Rise-time(sec)	Settling-time(sec)	Steady-state error
Tank1	Without controller	267	475	exist
Tank2	Without controller	186	332	exist
Tank1	PI-IMC	134	239	0
Tank2	PI-IMC	93.4	167	0
Tank1	BFO	1.6	2.53	0
Tank2	BFO	1.25	11.3	0
Tank1	PSO	1.06	1.68	0
Tank2	PSO	0.762	1.21	0
Tank1	G.A	0.15	0.267	0
Tank2	G.A	0.0878	0.157	0

5. CONCLUSION

In this work, the detailed study of (G.A) was described and implemented using MATLAB simulation for Quadruple tank system. The nonlinear model of the system developed and then linearized it for using in the control algorithm. It is shown by the simulation results that (G.A) technique solves the dynamic problem of the quadruple tank process and it is convenient for controller design under the requirement of the system. When comparing the proposed method (G.A), with the same system equation. (9) in [22], using(PI-IMC)and intelligent controller (BFO,PSO), it is clear that the design specifications (settling time, and rise time) are better. The (IMC) method needs more tuning and pre-filter to compensate steady-state error, so that using integral action and this added more cost. Liquid level of tank1 and tank2 can be settled to different set points and there is a considerable improvement in transient response.

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REFERENCES

[1] B.W.Bequette, 'Process control, Modeling, Design and Simulation', Prentice-Hall of India, 2003.

[2] Skogestad, S. and Postlethwaite, I. (2001), "Multivariable Feedback Control", Prentice Hall, New Jersey.

[3] Johansson KH, Horch A, Hansson A. "Teaching multivariable control using the quadruple tank process". In: Proceeding of the 38th conference on decision & control; December 1999.

[4] K. H. Johansson, "The quadruple-tank process: a multivariable laboratory process with an adjustable zero",*IEEE Trans. Control Syst.Technol.*, vol.8, no.3, pp.456-465, May. 2000. DOI: 10.1109/87.845876.

[5] D. A. Vijula, K. Anu, P. M. Honey, P. S. Poorna, "Mathematical Modelling of Quadruple Tank System" International Journal of Emerging Technology and Advanced Engineering, vol.3, Issue 12, December 2013.

[6] B. Moaveni, A. Khaki-Sedigh, "Input-output pairing for nonlinear multivariable systems", *J.Appl. Sci*, 22, 2007, 3492-3498 . DOI: 10.3923/jas.2007.3492.3498

[7] Garelli F, Mantz RJ, De Battista H.," Limiting interactions in decentralized control of MIMO systems", J. Process Control, 16, 2006, 473-483.

[8] Gatzke EP, Meadows ES, Wang C, Doyle III FJ," Model based control of a four-tank system", *Comput. Chem. Eng*, 24, 2000, 1503-1509. /doi.org/10.1016/S0098-1354(00)00555-X

[9] Mercangoz M, Doyle III FJ. Distributed model predictive control of an experimental four- tank system, *J. Process Control*, 17, 2007, 297-308.

[10] Henriksson D, Cervin A, Akesson J, Arzen K,"On dynamic real-time scheduling of model predictive controllers", 41st IEEE Conference on Decision and Control, Las Vegas, 2002, 1325-1330. DOI: 10.1109/CDC.2002.1184699

[11] Mukesh D. Patil, Ravindra S. Patil, Pravin G. Patil," Multivariable Control System Design for Quadruple Tank Process using Quantitative Feedback Theory (QFT)", ACEEE International Journal on Control System and Instrumentation, Vol. 1, No. 1, July 2010. DOI: Ol.ijcsi.01.01.04

[12] Rithu R. , R. Karthikeyan," Fuzzy tuned Proportional Integral controller with decouplers for quadruple tank process", IJCTA,Vol10,No9, 2017, pp. 831-839.

[13] M.Subba, R.Ananda ,Natarajan.M," Neural Network Modeling OF Quadruple-Tank MIMO System", Journal of Science ,Vol 5,No10,2015,P 935-940.

[14] Wael. A. Altabey," Model Optimal Control of the Four Tank System", International Journal of Systems Science and Applied Mathematics,Vol1,No4,2016.p30-41. doi: 10.11648/j.ijssam.20160104.11.

[15] Findeisen R, Allgower F, Biegler LT," Assessment and Future Directions of Nonlinear Model Predictive Control", Springer, Berlin, 2007, 604 .

[16] Barhoumi N, HadjSaid S, M'sahli F," Constrained nonlinear model predictive control of hybrid dynamic systems", *J. Auto. Syst. Eng*, 3, 2009, 46-56.

[17] Biswasa PP, Srivastavaa R, Raya S, Samanta A.," Sliding mode control of quadruple tank process", *Mechatronics*, 19, 2009, 548-561, DOI: 10.1016/i.mechtronics.2009.01.00.

[18] Labibi B, Marquez HJ, Chen T. Decentralized robust output feedback control for control affine nonlinear interconnected systems, *J. Process Control*, 19, 2009, 865-878.

[19] Bianchi FD, Mantz RJ, Christiansen CF. Multivariable PID control with set-point weighting via BMI optimisation, *Automatica*, 44, 2008, 472-478,. [20] Jesus Chacon Sombr, Jose Sanchez Moreno," Decentralised control of a quadruple tank plant with a decoupled event-based strategy", IFAC Conference on Advances in PID Control,PID'12,Brescia (Italy), March 28-30, 2012.

[21] R.Suja Mani Malar, T.Thyagarajan," Design of Decentralized Fuzzy Controllers for Quadruple tank Process", International Journal of Computer Science and Network Security, VOL.8 No.11, November 2008.

[22] Komathi C, Saidurga K, Sindhujaa S L," Performance Optimization of a Quadruple Tank System Using Particle Swarm Optimization Algorithm", ADVANCES in NATURAL and APPLIED SCIENCES, Vol11,No7,2017,P212-221.

[23] Jayaprakash J, SenthilRajan T, Harish Babu T," Analysis of Modelling Methods of Quadruple Tank System", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 3, No 8, August 2014.P 11552-11565.

[24] Karthick.S, , Lakshmi.P,Deepa.T," Comparison of fuzzy logic controller for a multivariable process", International Journal of Electrical and Electronics Engineering ,Vol3,No1, 2013.

[25] Jayaprakash.J, Hari Kumar M.E," State Variable analysis of four tank system", IEEE International Conference on Green Computing Communication and Electrical Engineering, March 2014. DOI: 10.1109/ICGCCEE.2014.6922341

[26] Katsuhiko Ogata, "Modern Control Engineering," Prentice Hall, Pearson Education International, vol. Fourth Edition, 2002.

[27] G. C., Goodwin, S.F., Grabe, "Control system design", Pearson Company,2000.

[28] P. Nordfeldt and T. Hagglund, "Decoupler and PID controller design of TITO systems", Journal of Process Control, vol.16, no.9, pp.923-936, 2006. DOI 10.1016/j.jprocont.2006.06.002

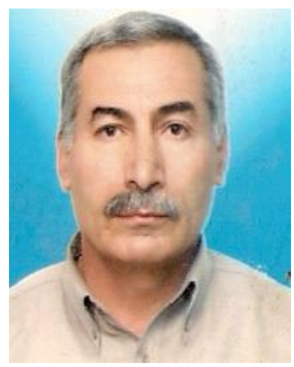
[29] B.Pradeepa, P.B.Nevetha, S.Abirami," Performance Comparison of Different Controllers for Flow Process", International Journal of Computer Application, Volume 90, No.19, March 2014,P17-21.

[30] Vipul Sharma, S.S. Pattnaik, Tanuj Garg, "A Review of Bacterial Foraging Optimization and Its Applications", National Conference on Future Aspects of Artificial intelligence in Industrial Automation (NCFAAIIA 2012).

[31] Qinghai Bai," Analysis of Particle Swarm Optimization Algorithm", Computer and Information Science,Vol3,No.1,2010.P180-184.

[32] D. E.Goldberg," Genetic Algorithms in Search Optimizations and Machine Learning", Addison, Wesley, 1989.

[33] Khrystyna Fedyanyna, Ievgeniia Kucher, Valery Severin," Optimal design of intelligent control systems of steam turbine using genetic algorithms", International Book Series "Information Science and Computing.



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