OPTIMIZATION OF PID CONTROLLER OF HIGHLY NONLINEAR COMPLEX SYSTEM USING TAGUCHI MPSO METHOD

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ABSTRACT : In many chemical and petrochemical processes plant having multiple input para and multiple output para for different processes. This research mainly focuses on searching the optimal controller structure by increasing the controllers' performance criteria. It is very difficult to control the highly nonlinear quadruple four tank system. It is always challenging due to the cross coupling effect of highly interacting system to stabilize and control of the mimo system. It is still a very big issue for control of nonlinear system. The Proposed algorithm for tuning of PID constant based on the new statically approach combined with soft computing techniques. One of the optimization of Stastical Taguchi method is to combine with mutation based particle swarm optimization hybrid algorithm tune the PID parameter. This tuning parameter optimized performance index of the nonlinear system. The tuning parameters of controller find optimal performance indices. It is computer based nonlinear system for performance analysis and check validation of proposed TMPSO algorithm. Laboratory is set up to communicate with MATLAB, LABVIEW and other controller platform. With the help of LABVIEW, implementation of proposed algorithm and output of the proposed algorithm validate with quadruple four tank laboratory set-up for testing. Check the performance indices based on the PID parameter tuning with proposed TMPSO algorithm and improve the response of different performance index for the experiment setup quadruple tank nonlinear system.

Keywords: **Quadruple Tank System, PID tuning, Performance Index, Taguchi MPSO algorithm**

INTRODUCTION

The global energy challenges of the world are increasingly becoming more demanding and complex. World's oil reserves need to be effectively optimized. The petroleum industry includes the global processes of exploration, extraction, refining, transportation (often by oil vessels on oceans, oil tankers on land and pipelines) and marketing petroleum products. Within the past 30 years, the world crude oil consumption had increased from to million barrels per day. This is alarming and therefore measures must be taken to meet up with these demands. There is a greater need to innovate, improve, design, optimize chemical processes, and improve the operations of equipment and facilities while making health, safety, and environment as a priority

The application of controllers in the process industry has dated far back as before the 1940s when John G. Zeigler and Nathaniel Nichols started their pioneer research about the behaviors of controllers as well as trying to develop good methods to be used in the tuning of the controller parameters. Afterwards, more recent advances in the application of control theory emerged as a result of various problems that needed to be resolved. A good example of recent control advancement is the use of optimal control methods that are formulated using the state-space models 1, and other varying formulations that are based on the process model (step and impulse responses), disturbance type (altered white noise, decaying and constant) as well as adaptation to time varying models. There is usually an optimal balance between the control error and the amount of control power used, and certain optimal criterion are being minimized in this case of optimal solution. Developing efficient control strategies that would be well suited for the control of multivariable systems has been quite challenging in many areas of engineering due to the cost and large amount of time spent on model identification. It is very important to have a prototype of the real process, so that the controller will inherently have knowledge about the process it will control. It is assumed that Taguchi MPSO controller would be preferred for most of the difficult control problems in the process and petrochemical industries, since it has so much impact on most industrial controls. The increased industries interest to use advanced control strategies which are robust and capable of achieving improved performance of complex industrial processes that are multivariable in nature, has made it an area of concern in the academia. And the engineering undergraduates and researchers, while in the quest for more understanding of the rigorous mathematics and modelling principles studied with pen and paper, they seem to get more knowledge and understanding of the behaviors of the complex industrial processes by performing experiments and at the same time making judgments with their own prior ideas.Stable control of nonlinear system should have good performance indices. Therefore, every nonlinear system which having a highly interacting, uncertain system must help together to acquired input and maintain output magnitude at specified level. QTS works by controlling level of liquid and output voltage which is fed into motor of tanks. It is very difficult for QTS system to control this closed-loop system for maintaining stable terminal output voltage. Appropriate controller to help QTS is PID controller because it has common structure, robust operation and wide range of application [34]. However, it is difficult to tune appropriate PID controller parameters because many industrial plants have problems with high order, delay time and nonlinearities [35]. From the past to present, there are numerous techniques are offered for tuning parameters of PID controller.

The evolution of PID controller starts from traditional tuning is Ziegler-Nichols method. It depends on the experience of the designer, so it is quite hard to determine optimal results [36].

Artificial intelligence (AI) techniques such as neural network technique, fuzzy logic, and neuro-fuzzy system were preferred by researchers. Neural network technique faces up to some problems about long convergence time and training process [37]. Fuzzy logic does not have self-learning process. It depends on the expertise of the designer in tuning membership functions [5]. Neuro-fuzzy logic is complicated method that takes a long time in learning process especially in non-linear dynamic behaviors system [38]. Recently, evolutionary computation techniques by random search methods, such as genetic algorithm (GA) and particle swarm optimization (PSO) have received much interest for searching high efficiency solution in optimization problem. The GA's natural genetic operations will take a heavy burden to computer in calculation. Moreover, the premature convergence of GA will reduce its performance in searching for the result [39].

The PSO is robust in finding the optimal solution in nonlinear problem. Strong points of PSO are stable convergence characteristic and take time consume shorter than other methods. All of these make PSO can produce a high quality result but it still suffers from memory capability and computational burden [40]. Nowadays, combination of two methods is proposed and got Quadruple tanks nonlinear system with PID controller much attention for improving the performance of tuning PID controller parameters. In 2012, Hany M. Hasanien suggested Taguchi combined genetic algorithm (TCGA) method for design optimization of PID controller in QTS system [42]. The result of TCGA is better than GA and PSO except for rising time. Long rising time means long convergence time and slow system. Therefore, QTS system would like the response that short rising time.

This Research presented the method for designing the best PID controller parameters for QTS system in synchronous generator by using Taguchi combined Mutation particle swarm optimization (TPSO) method. Taguchi method is used to design the lowest cases of experiments that represent the most efficiency comprehensive all cases without elimination of significant cases [11]. In Taguchi process, ANOM is used for obtaining approximate values of PID controller parameters. ANOVA is used to select the two most influential PID controller parameters. After that, PSO is used to optimize the two most importance parameters for PID controller to produce minimize the maximum percent overshoot, the rise time, the settling time and the steady-state error of terminal voltage response of synchronous generator. The computer program is used to simulate QTS system and write PSO's codes. Step response of this controller is compared with PSO and TCGA method. It shows the effective way to solve this problem with better response performance and robustness.

QUADRUPLE FOUR TANK SYSTEM

The process which has nonlinear characteristics has a more interaction of quadruple tank processes, which are touchstone processes used in many industrial applications. This frame up is very simple and rugged but still, the system would elaborate concerning multiple variable techniques. The process flow diagram is viewed in Figure 1. The main object has to maintain to the levels Y1 and Y2 at bottom tanks with prime movers. This mathematical model needed for the present practical lab includes and also the disturbing effect of flows in and out of the upper-level tanks. Input voltage is applied to prime movers V1 and V2 (input voltages to the pumps). This process is represented by the differential equations according to the material balance equation.

Processes are represented by equations

$$\frac{dh_1}{dt} = -\frac{a_1}{s_1(h_1)}\sqrt{2g|h_1|} + \frac{a_3}{s_1(h_1)}\sqrt{2g|h_3|} + \frac{\gamma_1 k_1 v_1}{s_1(h_1)}$$

$$\frac{dh_2}{dt} = -\frac{a_2}{s_2(h_2)}\sqrt{2g|h_2|} + \frac{a_4}{s_2(h_2)}\sqrt{2g|h_4|} + \frac{\gamma_2 k_2 v_2}{s_2(h_2)}$$

$$\frac{dh_3}{dt} = -\frac{a_3}{s_3}\sqrt{2g|h_3|} + \frac{(1-\gamma_2)k_2 v_2}{s_3} - \frac{k_{d_1} d_1}{s_3}$$

$$\frac{dh_4}{dt} = -\frac{a_4}{s_4}\sqrt{2g|h_4|} + \frac{(1-\gamma_1)k_1 v_1}{s_4} - \frac{k_{d_2} d_2}{s_4}$$

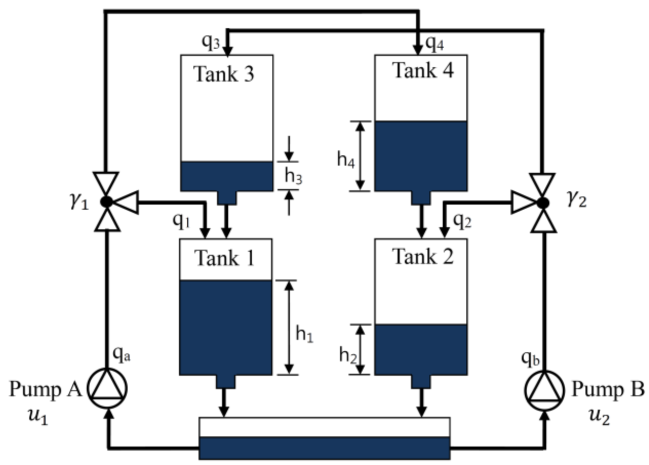

FIGURE: 2 Schematic diagram of Quadruple four Tank nonlinear system

This process presents interacting multiple variable dynamics, complex system because of each of the prime movers involves both of the outputs. This process exhibits nonlinear model and the nonlinear model converts to the linearized model of the quadruple-tank process has multi variable zero, which is to be situated on the left or the right half- s plane by adjusting the throttle valves position γ1 and γ2. It showed that the inverse response (non minimum phase) will happen when the value of this valve in the range of $0 < \gamma 1+ \gamma 2 < 1$ and minimum phase for $1 < \gamma 1+ \gamma 2 \leq 2$. The setting of the valve will be given to the overall system entirely dissimilar behavior from a multiple variable control point of view. Immeasurable disturbances can be enforced through forced water out of the main upper tanks and into the main bottom man made space small tank. It has been exhibited reject interference as well as mention covering the point. Using the multiple variable four tank process different aspects of multiple variable control systems can be illustrated. For example:

- Development and analysis of decoupling compensator.
- Development and analysis of state feedback compensator for different locations of the zeros.
- The valve settings effect on the location of the zeros.
- Recognize when a process is easy or not to control
- Design and evaluation of decentralized control.
- Development and analysis of mathematical model based predictive Strategy. Development and analysis of μ-analysis-based H∞ control.
- The locations of the zeros on the process output effect in different input directions

Controller Design

- The design method is compared with the various tuning method [10] of PID controller design using different artificial intelligent approaches

The tuning of the controller could be explained as maintaining the variable of the controller so that the system dynamic response is better or response based on the designer. There is numerous performance criteria for controller tuning that may accept, some of which are considered

- Keep the maximum deviation as minimum as possible
- Decreases the integral of errors until the process has settled at its settling positions
- Gaining short settling times
- Performance Criteria

In the process control system, two types of performance criteria are to be satisfied; one is steady state performance criteria and second dynamic performance criteria. Performance criteria based on the closed loop response of the system are Peak overshoot, Rise time, Settling time, Decay ratio and frequency of oscillation. In the specified characteristics can be used by controller designers as per controller selection and parameter value adjustment. In the Design of controller mainly concentrates to minimize overshoot, minimum settling time and another parameter which related to having given system. If consider process is nonlinear, the main characteristics' will be changed from one operating point to another operating point after that specific parameter tuning can produce the desired response at the only single operating point in the system. If change operating point in the system change controller tuning. Adaptive controller and self-tuning controllers are design required fine tuning for a specific application. PSO and GA provide the best adjustment of controller parameters in the case of changing process dynamics.[30]

Tuning based on integral criteria

The response of the complete closed loop system at t= o until steady state has been achieved can be utilized for the formulation of the dynamic performance criteria. Based on the closed response, these methods minimized the area under error vs. time curve. Significant of the Tuning methods to minimize the integral of error so that towards address for minimum error integral. Minimize of Integral of error is not possible directly because a very large negative error will be minimum value, so that the absolute error value or square of error value is taken and decrease.

Integral of squared area: ISE
Integral absolute error: IAE
Integral of time multiplied by absolute value of error: ITAE
Integral of time multiplied by Square value of error: ITSE

TAGUCHI METHOD (ANOVA)

The Taguchi method provides a very long meaning of explaining of the separate and mix results of different design principles based on the lowest number of trials (Al-Arifi et al., 2011) Taguchi approach for design variables is available in several categories as a result of an output of every variable to quality characteristics. The different levels of the process outcome are converts into s/n ratio. The standard ratio of signal to Signal to noise basically utilized are as follows: first is the Smaller value the Better, Second the Nominal value the Better, and third is the Higher value -The Better. This research study uses the ratio of Signal to Noise of the ISE and IAE performance to minimize the better stability of the nonlinear quadruple tank system process. The Signal to Noise ratio the Smaller-The Better (STB), characteristics is as follows (Lin and Chou, 2010):

$$\frac{S}{N}=-\log\left(\frac{1}{n}\sum vi^2\right)$$

Where, n is the number of counts under the same design parameters, yi indicates the measured results and i presents the number of application based variables in the Taguchi OA. An output of S/N ratio figure of paramater levels indicates a better concept with preferable quality within the specified values. The ANOVA techniques utilized for in the Taguchi is a novel statistical approach first excepted to an analysis of the major values of application parameters and also the output of each variable, yi denoted the measured output results and i denotes the number of application parameters available with the Taguchi Orthogonal Array due to ratio of signal and noise, Effect of the Process parameter obtain based on ANOVA. The output of S/N ratio diagram of variable values shows a application with considerable prime within the specified value of variables.

MUTATUIN COMBINED WITH PARTICLE SWARM OPTIMIZATION

The roots of PSO were instigated through the social behavior of fish schooling or bird flocking. Eberhart and Kennedy counseled the particle swarm computer program optimization pso methodology in 1995. In the search space indicates a good performance for each particle to the minimization specific task and representing as a bunch of different specific variables. This is linked with two path which name is the positioning and velocity path, which called name is the position and acceleration vectors In nth -dimensional search space, the two vectors associated with each particle i are Xi = (xi,1, xi,2, . . ., xi,n) and Vi =(vi,1, vi,2, . . ., vi, n), respectively. Every particle changes the levels its result will depend on it is own good survey and the good swarm overall involvement to search it is good fitness level using iterative changing. Moving ahead this iteration process, the change of position and velocity of each and every particle are evaluated as shown in the equation. The global best position and acceleration are change after each iteration value. Equation suggests the updated design variables after mutation of each up to date particle from previous equation. The proposed algorithms were designed to continuous change parameter in specified equation for specific method up to reach termination states.

EXPERIMENT SET UP DETAIL

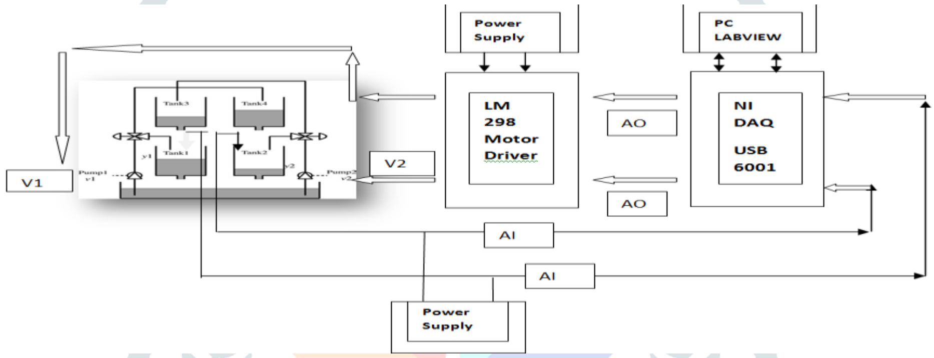

FIGURE: 3 Schematic Diagram of Quadruple Four Tanks System

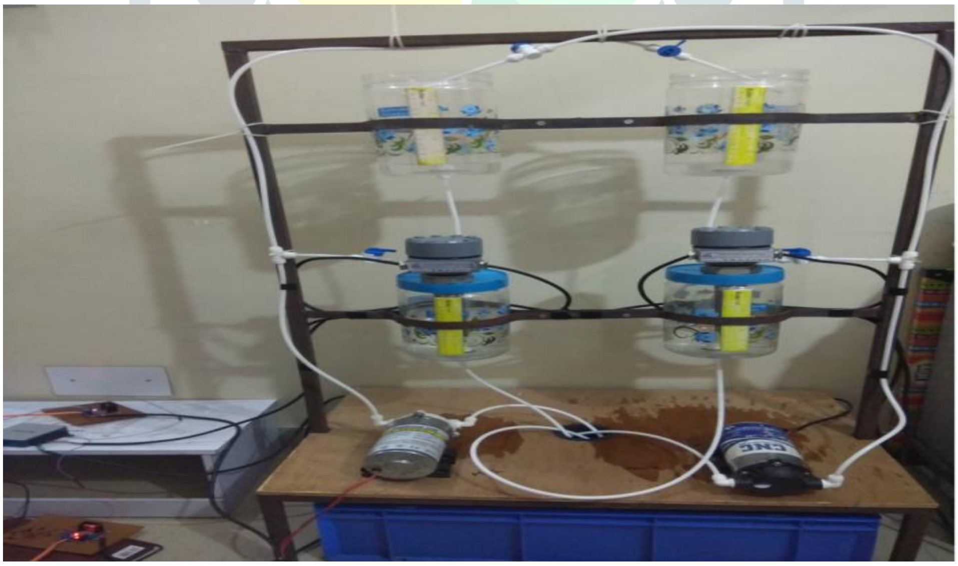

FIGURE: 4 Experiment Actual Quadruple Four Tanks System

In the quadruple four tanks system having two manipulated parameter as output of PWM signal to motor. The experiment laboratory setup involve of four tanks are interconnected in the process to control two parameter as level of the bottom tank1 and tank2. Fig: 1, seen the schematic diagram of nonlinear four tanks system. Output voltage is controlled through two pumps and two three way valves transport liquid in different manners. There are two three way valves which are used to decide the interaction between incoming and outgoing applied voltage to two pumps for controlling the flow of liquid. Level of the liquid is input of the system. Capacitive level transmitter is used for measurement of level. Due to effect of coupling disturb the bottom level of the liquid so that system going to unstable. Now figure 2 indicates experiment setup for implementing proposed algorithm.

Laboratory setup consists of cost ion steel pipe structure to hold whole system elements plastic bottom as beakers, 1/8 " piping, pumps having 24 volt DC 1.2 amp capacity and three way valves. Opening and closing of valves γ1 and γ2 spit the direction of liquid to bottom tank or upper tank and it is determine the interaction between two inputs and output of the nonlinear system. We used Capvel capacitive indicator cum transmitter for measurement of level. The output of transmitter calibrated level in terms of 1 to 5Vdc, its measurement span 15 to 3000pF, response time 0.5 to 5 sec. we does not necessary to use any signal conditioning circuit. Output of transmitter interfacing with NI USB based DAQ card directly and acquired signal in Lab view software user interface. NI DAQ card consist of 2 channels Analog Output, 4 channels Analog input, 8 channels Digital Input, 8 channel Digital Output. National instrument lab view software consists of PID tool kit to design and development of user interface with hardware and also implement tuning parameter real time for proposed algorithms.

RESULT AND DISCUSSION

Fig 1 of the response of simulation and experiment setup of nonlinear quadruple four tanks system by implementing Taguchi MPSO PID tuning controller with Kp and Ki parameter of both controller. For step input consider as level (height of tank). In the multiple inputs multiple outputs system has worked with two different minimum and non minimum phase based on value of the three way valve position γ1 and γ2. The value of PID tuning by proposed algorithm. So controller tries to reduce the coupling effect between input and output. Response of the simulation and experiment setup given in table and also improve the response of performance index criteria ISE and IAE. The propose algorithm implemented with this setup.

TABLE I: Comparison Performance Index Taguchi based Simulation and Experiment data with MPSO for QTS (minimum phase)

Methods	Minimum phase (γ1= 0.6 and γ2=0.7)			
	Level 1 (5 cm)		Level 2 (5cm)	
	ISE	IAE	ISE	IAE
Simulation Data	10.02	5.62	10.02	5.62
Experiment Data	18.09	10.66	19.09	10.03

TABLE II: Comparison Performance Index Taguchi based Simulation and Experiment Data with MPSO for QTS (minimum phase)

Methods	Non Minimum phase (γ1= 0.3 and γ2=0.4)			
	Level 1		Level 2	
	ISE	IAE	ISE	IAE
Simulation Data	10.02	7.62	10.02	6.62
Experiment Data	14.34	9.661	15.34	9.761

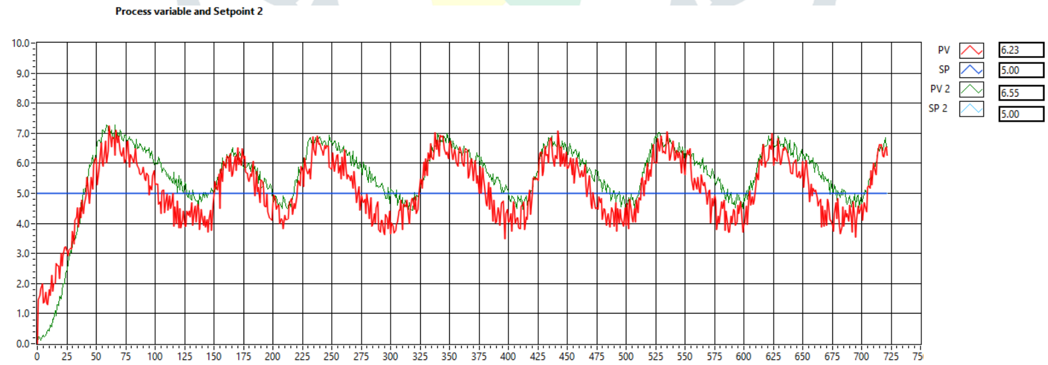

FIGURE: 6 Experiment output responses of system for Taguchi MPSO in Minimum phase

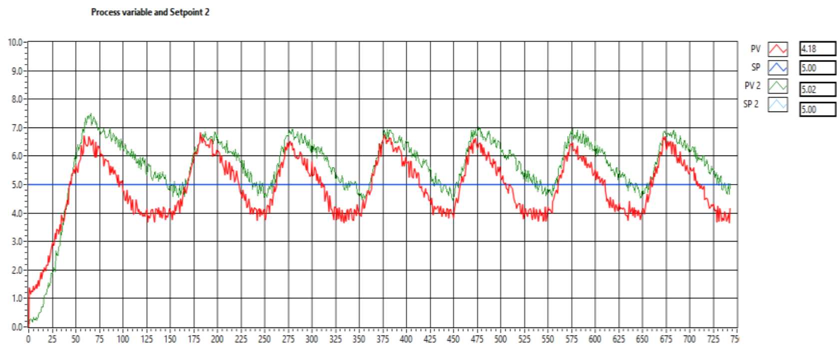

FIGURE: 7 Experiment output responses of system for Taguchi MPSO in Non Minimum phase

CONCLUSION

Optimization based on Taguchi based MPSO algorithm for tuning of PID controller is developed using Lab view hardware and software experimental setup for analysis and validation purpose. This proposed algorithm implemented with laboratory setup to improve performance index as compared to other AI techniques. The performance of the system tested gives fine tuning parameter for said controller for different coupling effect along with multiple input outputs. The results compared with simulation and experiment setup time domain specification as well as performance index is improved. The proposed algorithm validate with quadruple four tank system.

This research paper presented for finding the best optimal solution for the nonlinear dynamic system. These techniques to find optimize the parameter of the controller for multiple inputs and multiple output dynamic system using Taguchi statistical method based on MPSO techniques. The effect indicate that taguchi based MPSO strategies can act as quality strategies of the MIMO nonlinear process and might be extended to different nonlinear method controller parameter for the industrial process control system.

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