Design Of Gain Scheduled PID Controller For Nonlinear Liquidlevel System

SheetalGawale,V.K.Jadhav, C.B.Kadu, P.S.Vikhe, S. M. Turkane

Abstract: This paper exhibits the design of gain scheduling PID controller for controlling the dynamics of a nonlinear liquid level system. The gain scheduling PID controller controls the level of the water in the tank. The Ziegler-Nichol tuning technique used to tune the parameters of gain scheduling PID controller. Here the meta-heuristic methodology known as Firefly Algorithm (FA) for the optimization of error percentage and improving the accuracy is introduced. Our newly designed technique accomplishes an accuracy of up to 93%. The newly designed strategies utilize in this explore achieved using MATLAB/SIMULINK environment. Thus, the theoretical analysis and simulation are shown to confirm the effectiveness of the proposed methodology in the control system.

Keywords: PID controller, Gain-scheduling, Firefly Algorithm (FA),Water tank.

1. INTRODUCTION

To find the relevant subsystems with changes in process kinetics is some more difficult. The effect of parameter variants can be decreased by changing the controller's parameter on the sub-parameters [1, 2]. The feedback gains adjusted using the losses of the gain, as an adjustment control system. An essential problem in the design of the systems with resource planning is to find appropriate planning variants. It is usually done on physics [3,4]. When planning variables are determined, the controller parameters are computed in several operating systems using some appropriate design methods.Each control level is adjusted or adjusted to control the stability and act of the system evaluated by simulation [5, 6]. It is used for sturdy control designobjectplanning PID controller design achievement planning is an adaptive control system. This method is suitable if plant parameters change frequently and more.In this way, the control parameters were collected and set.Compared to PID's predefined PID controller has five adjustment parameters [7, 8]. Linear Parameter Varying Control (LPVC) has achieved more interest in researches because the controller gains are adapted based on scheduling parameters. The resulting scheduling parameters denote the specific operating point of a process. In most of the industries, such as chemical industries and aerospace, gain-scheduling controllers play a vital role [9, 10]. In a case where the dynamics of the plant changes for different operating conditions, a gain scheduling controller can be used.

2. RELATED WORK

The free-range control technique provides guidelines for controlling linear controls. Limitations of PI controllers and deliberate control performance for cone tank operation. This challenge commenced the negative electricity price situation at times of high supply of renewable power or low power demand. These requirements put new operating challenges on both negative andpositive load gradients. Also, the dynamic response of thermal power station for sudden load change in the grid even at startup and shutdown conditions.Considering this in mind, Ahmad Salehietal.[11,12] described the FO differential equations to realize challenging control requirements that have recently caught the center of attention of both academic and industrial fields in the nuclear sector.
The PID controller does not guarantee the optimal control of the system or its stability. There is no guarantee to work correctly. In the PID controller, the best parameters are the most challenging task of finding systems becauseit causes a delay. To improve this, Mohamed Issaetal.[13] definedthe Meta-heuristics algorithm is a systematic strategy similar to its behavior from social and environmental settings to improve engineering problems.PID controller parameters can use meta-summary to select the best combination this gives an efficient static responseThis is a firm definition of the traditional control approach; those PID parameters depend on the wrong measurement; current physical and environmental conditions will significantly decrease. To avoid this, Wei Wang et al. [15] proposed the PID controller with FLC (logic control strategy) with the use of these techniques they can gain accurate measurement. Also, minimize the challenges in a control system in a hybrid manner with high accuracy.Therefore,C.B.Kadu&D.Sakhareproposedan Inverse response of the boiler drum water level. Steam drum level is one of the significant causesof boiler trips and downtime affected by the phenomena of swell and shrink; it is a difficult parameter to control accurately. The Conventional PID cannot give satisfactory results for the boiler drum level. The self-adaptive fuzzy PID controller is better than IMC controllers, which help to reduce, undershoot &overshoot [14, 15].

3. DESIGN OF GAIN SCHEDULING PID CONTROLLER

The proposed method is to implement a gain scheduling PID controller for the nonlinear varying system.Fig.1 shows the block diagram for the proposed methodology, theProportional-Integral-Derivative (PID) controllers are the

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most favored. To calculate the gain here, use the LPV system; finally, the optimization problem solved using firefly, and the best solution evaluated.

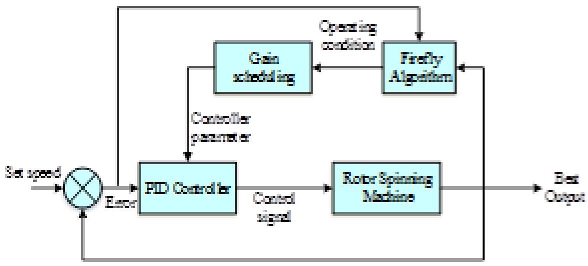

***Figure: 1** Schematic Representation of the proposed method*

3.1 Controller Design:

Gain scheduling PID controlleris one of the valuable controller configuration approach used in nonlinear and linear parameter varying systems for process control. Proportional integral derivative (PID) control is one of the simple control structures which are appreciated by plant operators and which they generally found simple to tune. Since various control systems employing PID controller have demonstrated to be attractive, it is still used in an extensive range of applications in industrial control. The PID controller uses operational amplifiers to derive proportional, integral, and derivative terms. The performance of the system can be enhanced by adjusting the values of k_p , k_i k_d and of the PID controller. The PID gains also play a vital role in estimating the nature of the control system using some tuning techniques. The proportional controller (k_p) is used to guarantee that the output reaches the reference input. However, the output of the system will never achieve zero steady-state error. Hence to acquire a very less steady-state error, an integral controller (k_i) is used in the system. The recital of the system is improved using the derivative controller (k_d). The values of k_p , k_i and k_d can be adjusted manually to deliver proper output.The PID control is defined as follows,

$$u^*_{PID} = k_p e^*\left(t^\circ\right) + k_i \int_0^{t^\circ} e^*\left(\tau^\circ\right) d\tau^\circ + k_d \frac{de^*\left(t^\circ\right)}{dt^\circ} \tag{13}$$

Where u^*_{PID} is the control variable, $e^*\left(t^\circ\right)$ is the error and k_p k_i , k_d are the control gains respectively from eqn.13.

The error is expressed as,

$$e^*\left(t^\circ\right) = u^*\left(t^\circ\right) - v^*\left(t^\circ\right) \tag{14}$$

Where $u^*\left(t^\circ\right)$ the reference values and $v^*\left(t^\circ\right)$ is the process output. The error value calculated based on the eqn.14.

In this paper, the gain scheduling PID controller designed to control the level of the water tank. Gain scheduling is a strategy trading off between the linear system and the nonlinear system.Gain Scheduling is an expansion of linear control design methods.It has been an acknowledged technique for controlling the parameters of the water tank.

3.2 Model of the variable area liquid level system

The conical tank system is an industrial apparatus utilized for the water tank. It frequently works in a dynamic state; hence, it is hard to control the tank system. The active description of the process is characterized.Gain scheduling PID controller used in tank level system to controls the flowrate and theoutput water level in the tank. The conical tank is a superior instance for a nonlinear system and very less expensive. It is very easy to test and implement various controllers for studying and analysis purposes. The area of the conical tank increases when the height of the tank increases. The liquidlevel in the tank is maintained at a constant value by adjusting the inflow tothe tank. The outflow is adjusted using a manualvalve. This offers resistance to the outflow. Due tothis variable area, the relation between the inflow (input) and the Liquid level (output) is nonlinear. A number step test has tobe conducted for each region to obtain the transfer.Once the desiredoperation region is decided, the Gain scheduling PID controller has tobe designed to control the level effectively. Here, gain scheduling controller are studied and comparedits performance.

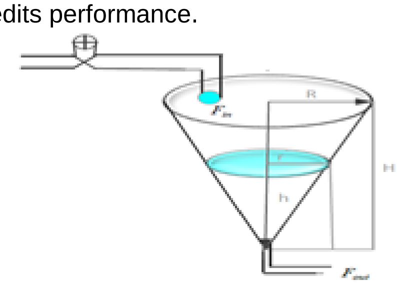

***Figure:2Schematic** diagrams of variable area water tank level system*

3.3Mathematical Model

The system denoted the input and output system; as we can see in the diagram, the inlet flow to the tank feeds the water into the tank, and controlled output drains the water from the tank. Control algorithm to the Single Input Single Output (SISO)systemby Eqn. (1) and (2). Consider the conical tank level system.

$$\tan\theta = \frac{p}{q} = \frac{R}{Q} \tag{1}$$

Where θ is represent the angle of the conical tank level system, p is the radius of the liquid in the tank, q is the height of the liquid in the tank. R The top radius of the conical tank and Q is the total height of the conical tank.

$$B = \pi p^2 \tag{2}$$

$$B = \pi \frac{p^2 q^2}{Q^2} \tag{3}$$

Then, q is denoting the height of the liquid, and Q is a maximum height of the tank; for B is the area of the tank level system, and P is the maximum radius of the tank by Eqn.(3). Then the differentiation by Eqn.(4) and (5).

$$C = \frac{1}{3}\pi p^2 q \tag{4}$$

$$\frac{dC}{dt}=\frac{1}{3}[B\frac{dq}{dt}+q\frac{dB}{dt}] \quad (5)$$

$$\frac{dC}{dt}=B\frac{dq}{dt} \quad (6)$$

WhereC represents the volume of the system, the calculate input and output flow feeding the tank.The mass balance equation conical tank shown in equation (7) and (8)

$$H_{in}H_{out}=B\frac{dq}{dt} \quad (7)$$

$$H_{out}(s)=\frac{q(s)}{K} \quad (8)$$

Where H_{in} is represents flow feeding the tank.The rate of the accumulator is equal to the inflow rate reduction of outflow rate is shown in Eqn.(9)

$$H_{in}(s)-H_{out}(s)=Bq(s)L \quad (9)$$

The transfer function of the regular tankshown in Eqn. (10)

$$\frac{q(s)}{H_{in}(s)}=[\frac{M}{M\frac{\pi P^2 q^2}{Q^2}S+1}] \quad (10)$$

Where M is constant.Consider a nonlinear state-space model, by Eqn. (11) and (12)

$$X \;=r(X_t)+o(X_t)V^{\bullet} \quad (11)$$

$$U^{\bullet}=P(X_t) \quad (12)$$

Where $X_t,U^{\bullet},V^{\bullet}$ is represents the state, input, and output vectors, respectively, r is a statevariable.The transfer function is obtained from theproceeding s of gain scheduling PID controller for a conical tank system. The transfer function is shown in Eqn. (13)

$$H(s)=\frac{12.87e^{-0.1s}}{46.9s+1} \quad (13)$$

Feedforward conditions of gain scheduling PID controller and conical tank transfer function, as shown in Eqn. (14)

$$\frac{h(s)}{F_{in}(s)}=\frac{C_C C}{1+C_C C} \quad (14)$$

The transfer function obtained from the proceeding of gain scheduling PID controller. Thetransfer function, as shown in Eqn. (15)

$$H_C(s)=K_p(1+T_d s+\frac{1}{T_i s}) \quad (15)$$

Where Proportional gain K_p.The derivative constant T_d. The integral timeconstant T_i.

4.0 FireflyAlgorithm(FA):

Nature-inspired heuristic algorithms are getting stronger in solving modern global optimization problems, particularly because of complex nonlinear optimization issues.Firefly algorithm is one of the ongoing swarm intelligence techniques proposed by Yang in 2008, depending upon the behavior of the flashing light of fireflies. The pattern of flashes changes from one type of firefly to others.The flashing light of the fireflies enables them to attract one another, realize their partners, and reach their prey. The bright fireflies effortlessly entice the less bright fireflies. By a bioluminescence procedure, the flashing light made. The brightness of each firefly means the quality of the solutions.A sort of stochastic algorithmused for solving the hardest optimization problems.

FIREFLY ALGORITHM

1 Generate the firefly population initially through random generation
2 Obtain the fitness and find p best and g best.
3 The initial fireflies population is the optimized population derived from PSO
4 While (stopping criteria is satisfied)
5 For i=1: n
6 For j=1: n
7 If light (i)>light(j)
8 Firefly(j) is stepping to firefly (i) with the updated light intensity
9 else
10 Firefly(j)is moving randomly
11 end if
12 Obtain the light intensity and find the new solution.
13 end j
14 end i
15 end while
16 Sort the light intensity of the fireflies in the descending order.
17 Realize the optimal solution (reduce error).

The first step is initializing FA parameters, and the objective function is characterized. At that point, the initial population for the given problem is created.After that, the fitness and light intensity for all fireflies assessed. Then the attractiveness and distance of each firefly are calculated, and lastly, the best solution is found. These steps are repeated until the maximum number of generations is reached.

The attractiveness function of a firefly is expressed as, shown in equation (15)

$$\beta^{\bullet}(r^{\bullet})=\beta_{\circ}^{\bullet}\exp\left(-\gamma^{\bullet}r^{\bullet 2}\right) \quad (16)$$

The nature of each firefly is calculated by the Eqn.16, and the best solution is resolved. The distance of separation between any two fireflies i and j at $x_i^{\bullet}$ and $x_j^{\bullet}$ can be characterized as, shown in Eqn. (16) and (17)

$$r_{ij}^{\bullet}=\left\|x_i^{\bullet}-x_j^{\bullet}\right\| \quad (17)$$

$$r_{ij}^{\bullet}=\sqrt{\sum_{k=1}^{d}\left(x_{i,k}^{\bullet}-x_{j,k}^{\bullet}\right)^2} \quad (18)$$

$$x_i^{\bullet}=x_i^{\bullet}+\beta_{\circ}^{\bullet}e^{\left(-\gamma^{\bullet}r_{i,j}^{\bullet 2}\right)}\left(x_i^{\bullet}-x_j^{\bullet}\right)+\alpha^{\bullet}\left(rand-\frac{1}{2}\right) \quad (19)$$

$$x_i^{\bullet} = x_i^{\bullet} + \alpha^{\bullet} * \left(rand - \frac{1}{2} \right) \tag{20}$$

The movement of a firefly i that is pulled in by a brighter firefly j is denoted by the Eqn.(19) And (20), the first term denotes the current position of a firefly, the second term represents the attractiveness of a firefly and the third term utilized for the random movement of a firefly.

5.RESULTS AND DISCUSSION

Our newly designed methodologies are executed in MATLAB/SIMULINK environment. It is a numerical and restrictive programming language by Math Work. Fig.3 shows the linear analysis of tank amplitude, fig.4 shows linear analysis of phase, frequency, and magnitude.

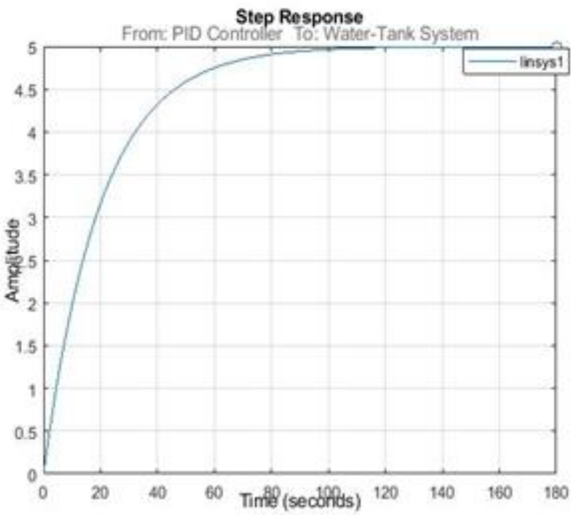

Figure. 3 *Time vs. amplitude in linear analysis*

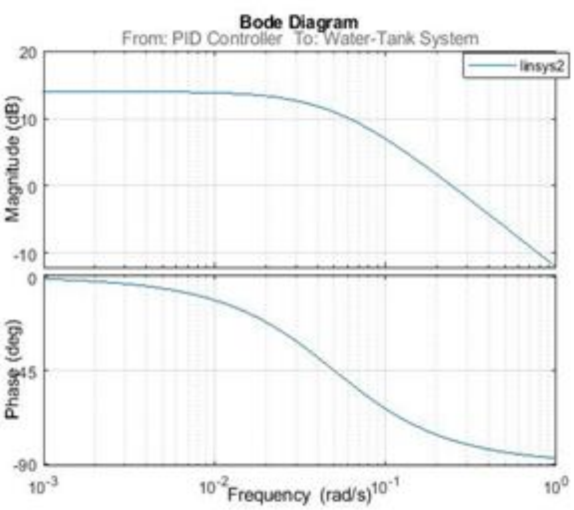

Figure. 4 *Linear analysis frequency, phase, and magnitude*

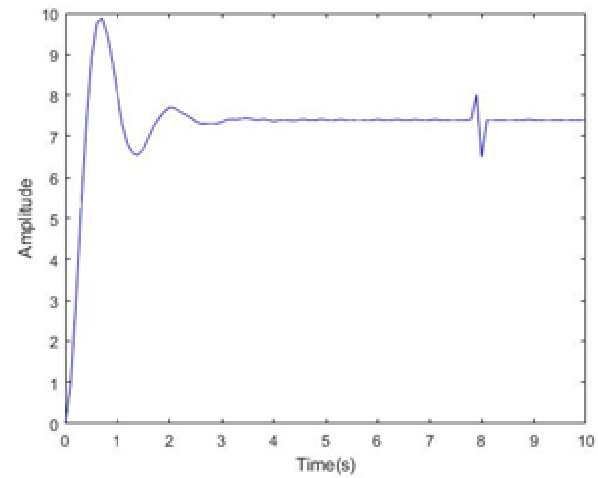

Figure:5*:Disturbance Rejection*

The percentage of error in the conical water tank determined using the firefly algorithm (FA), as shown in Fig.5 and gain scheduling PID controller, can optimize the error percentage in Table.1.Compared with the conventional PID controller and ZN-Conventional PID controller; however,onecan achieve a better result for our designed technique.

Table.1 *Comparison with existing controllers*

Type of controllers	%error
Conventional PID [18]	0.2
ZN-Conventional PID [16]	8.56
Gain schedulingPID (Proposed)	0.083

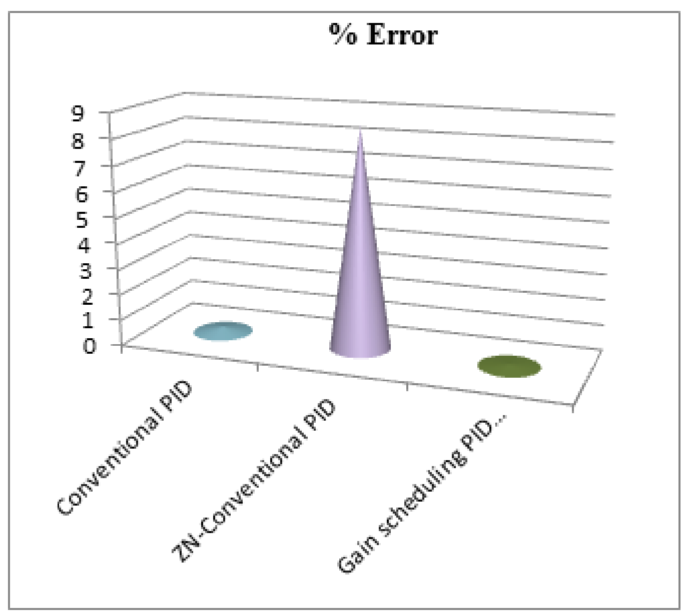

Figure: 5 *Comparison of percentage error with existing controller*

$$\text{Accuracy} = \frac{(TN + TP)}{(TN + TP + FN + FP)} \tag{21}$$

To obtain high accuracy by using Eqn.(20), the population of fireflies and the number of iteration must be high. The accuracy of the system calculated by Eqn. (21) where TN is true negative, TP is truly positive, FN is a false negative, and FP is false positive

6. CONCLUSION:

The main aim of conducting this research is to design a proper gain-scheduling controller for controlling the highly nonlinear system by Linear Parameter Varying (LPV) models. Gain scheduling PID controller is one of the simple control structures by process operation, and they found a generally simple tune. The designed gain scheduling PID controller used in the tank level system to achieve the flow rate and the control output water level in the tank. By using the firefly algorithm (FA) enhances the level control performance by lowering the percentage error and increasing the accuracy in the normal and contingency conditions.

REFERENCE

[1] M. Villani, L. Sani, R. Pecori, M. Amoretti, A. Roli, M. Mordonini, R. Serra, and S. Cagnoni, "An Iterative Information-Theoretic Approach to the Detection of Structures in Complex Systems," Complexity, vol. 2018, pp. 1–15, Nov. 2018.

[2] M. Neuvonen, E. K. Tarkiainen, A. Tornio, P. Hirvensalo, T. Tapaninen, M. Paile-Hyvärinen, M. K. Itkonen, M. T. Holmberg, V. Kärjä, V. T. Männistö, P. J. Neuvonen, J. Pihlajamäki, J. T. Backman, and M. Niemi, "Effects of Genetic Variants on Carboxylesterase 1 Gene Expression, and Clopidogrel Pharmacokinetics and Antiplatelet Effects," Basic & Clinical Pharmacology & Toxicology, vol. 122, no. 3, pp. 341–345, Nov. 2017.

[3] J. Driffill and P. de Grauwe, "The Economics of Monetary Integration.," Economica, vol. 61, no. 243, p. 401, Aug. 1994.

[4] Mason, Jonathan Hugh. "Quantitative cone-beam computed tomography reconstruction for radiotherapy planning." (2018).

[5] M. Rahmani, M. Kaykhaii, and M. Sasani, "Application of Taguchi L16 design method for comparative study of ability of 3A zeolite in removal of Rhodamine B and Malachite green from environmental water samples," SpectrochimicaActa Part A: Molecular and Biomolecular Spectroscopy, vol. 188, pp. 164–169, Jan. 2018.

[6] C. W. de Silva,e "Fuzzy Logic Control," Intelligent Control, pp. 69–101.

[7] C. B. Anderson, B. K. Franzmayr, S. W. Hong, A. C. Larking, T. C. van Stijn, R. Tan, R. Moraga, M. J. Faville, and A. G. Griffiths, "Protocol: a versatile, inexpensive, high-throughput plant genomic DNA extraction method suitable for genotyping-by-sequencing," Plant Methods, vol. 14, no. 1, Aug. 2018.

[8] C. Proestos, P. Zoumpoulakis, and V. J. Sinanoglou, "Isolation and Characterization of Phenolic Compounds From Selected Foods of Plant Origin Using Modern Spectroscopic Approaches," Studies in Natural Products Chemistry, pp. 203–220, 2018.

[9] M. Pradeep, B. Sharmila, D. Devasena, and K. Srinivasan,"PIDand<tex>$\text{PI}^{\lambda}\text{D}{\mu}$</tex>Controller Implementation for Speed Control Analysis of Two Mass Drive System," 2018 International Conference on Communication and Signal Processing (ICCSP), Apr. 2018.

[10] Wadhwa, Anil, AshishRanjanJha, Chandra Saravanan, Asit Kumar Das, PinakiranjanSankarprasadPatra, SukumarMandal, Praveen Kumar Chinthala, et al. "System and method for preparing hydrocarbon blend from multiple component streams." U.S. Patent 9,944,867, issued April 17, 2018.

[11] Arasu, S. Kapil, and J. Prakash. "Experimental validation of predictor-corrector approach based control schemes on the laboratory scale non-linear system." ISA transactions 76 (2018): 188-196.

[12] Salehi, Ahmad, OmidSafarzadeh, and Mohammad HosseinKazemi. "Fractional order PID control of steam generator water level for nuclear steam supply systems." Nuclear Engineering and Design 342 (2019): 45-59.

[13] Issa, M., Elbaset, A. A., Hassanien, A. E., &Ziedan, I. (2019). PID Controller Tuning Parameters Using Meta-heuristics Algorithms: Comparative Analysis. In Machine Learning Paradigms: Theory and Application (pp. 413-430). Springer, Cham.

[14] S. S. Deshpande and C. B. Kadu, "Design of multi scale PID controller for Temperature process," 2016 International Conference on Automatic Control and Dynamic Optimization Techniques (ICACDOT), Sep. 2016.

[15] C.B.Kadu and D.S.Sakhare, "Improved Inverse Response of Boiler Drum Level using Fuzzy Self Adaptive PID Controller," International Journal of Engineering Trends and Technology, vol. 19, no. 3, pp. 140–144, Jan. 2015.