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Performance Analysis of Intelligent Controller and Classical PID Controller for Conical Tank System

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***Abstract*— Linear control systems can be easily tuned using classical tuning techniques such as the Ziegler-Nichols and Cohen-Coon tuning formulae. It has been found that these conventional tuning methods result in an unsatisfactory control performance when they are used for processes experiencing the negative destabilizing effects of strong nonlinearities. It is due to this reason that control practitioners often prefer to tune most nonlinear systems using trial and error tuning, or intuitive tuning. Therefore, a need exists for the development of a suitable tuning technique that is applicable for an extensive range of control loops that do not respond satisfactorily to conventional tuning.**

Emerging technologies such as Swarm Intelligence (SI) have been utilized to solve many non-linear engineering problems. Particle Swarm Optimization (PSO) was developed by Eberhart and Kennedy (1995) and after being inspired by the study of bird flocking behavior by biologist Frank Heppner. It was observed that each individual exchanges previous experience, hence knowledge of the "best position" attained by an individual becomes globally known. The problem of identifying the PID controller parameters is considered as an optimization problem in the study. In the study, an attempt to determine the PID parameters has been made using PSO technique. A broad range of typical process models commonly encountered in industry is used to assess the effectiveness of the PSO methodology.

***Index Terms*— PSO, PID control**

I. INTRODUCTION

In control systems, there are various generic systems and methods which are encountered in all areas of industry and technology. In the process industries, such as petro-chemical industries, paper making and water treatment industries, the control of liquid level in tanks and flow between tanks is a basic problem. Serious difficulties arise in a system when the liquid level in a chosen process varies. A level that is too high may upset reaction equilibrium which in turn causes damage to equipment, or results in spillage of valuable or perilous material. If the level is too low, it may have bad consequences for the sequential operations. So control of liquid level is an important and common task in process industries [1].

Conical tanks find wide applications in process industries. They are widely used in hydrometallurgical industries, food process industries and wastewater treatment industries. Conical tank is considered as a nonlinear system because of its constantly changing cross sectional area [2]. Control theory deals with the design of linear controllers with linear systems. Conventional PID controller proved to be a perfect controller for simple and linear processes. The controller parameters have to be continuously adjusted when it comes to the control of non-linear and multivariable processes [3].

Conventional PID controllers are widely used in industries since they are simple, robust and common to the field operator. In practical, the systems are not precisely linear but may be represented as linearized models around a nominal operating point. The controller parameters tuned at that point may not reflect the real-time system characteristics due to variations in the process parameters. The Particle Swarm Optimization algorithm (abbreviated as PSO) is a novel population-based stochastic search algorithm and an alternative solution to the complex non-linear optimization problem [4].

II. DESIGN OF PID CONTROLLER

PID controllers are still widely used in many industrial control systems. The simplicity and transparency of PID control mechanism, the availability of a large number of highly efficient, reliable, and cost-effective commercial PID control modules, and their acceptance from the operators are among the reasons for their popularity.

PID stands for proportional-integral-derivative controller. Output of this controller is a control variable which is a function of its input variable i.e. an error signal. Transfer Function of the PID controller is given by:

$$\frac{U(s)}{E(s)} = \frac{K_d\, s^2 + K_p\, s + K_i}{s} \qquad (1)$$

where Kp is the Proportional gain, Ki is the Integral gain and Kd is the Derivative gain.

It is important to look at what is the aim of the controller tuning. If possible, one would like to achieve both of the following objectives for the control system: Fast responses and Good stability. Unfortunately, for most practical processes being controlled with a PID controller, these two wishes cannot be achieved simultaneously. Mostly the following features are achieved:

- Faster responses, with the worse stability, and
- Better stability, with the slower response.

For a control system, it is more important that it has better stability in comparison to being fast in response. Fig.1 illustrates the above phenomenon. It shows the response in the process output variable due to a step change of the set-point. The response corresponds to three different gains in a simulated control system.

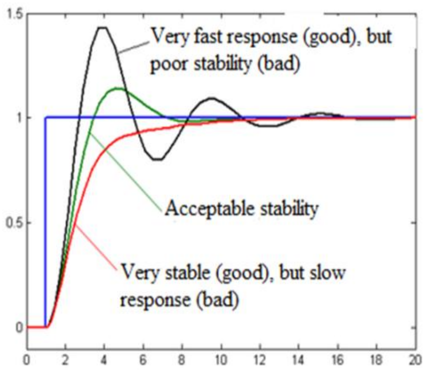

Fig. 1 Modes of Stability of a Control System

A PID controller has been designed for the conical tank system using MATLAB/ SIMULINK PID tuner block. The SIMULINK model is shown in Fig. 2.

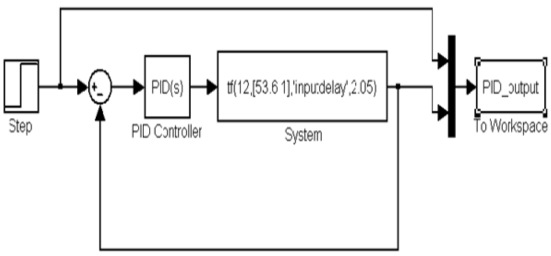

Fig. 2 Simulink Model of PID Controller

The desired closed loop dynamics is obtained by adjusting the three parameters K_P, K_I and K_D, often iteratively by "tuning". PID controllers are important type of controller and provide good static and dynamic response, for this its parameters must be properly tuned. Performance of PID depends on the gain parameters, so we need to adjust them. Tuning the controller parameters is a crucial issue.

Stability can often be ensured using only the proportional term. The integral term permits the rejection of a step disturbance (often a striking specification in process control). The derivative term is used to provide damping or shaping of the response. The proportional, integral, and derivative terms are summed to calculate the output of the PID controller.

$$u(t) = K_p e + K_i \int e \, dt + K_d \qquad (2)$$

If u(t) is the control signal sent to the system, y(t) is the measured output and r(t) is the desired output, and tracking error e(t) = r(t) − y(t). A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then sending a corrective action that can adjust the process accordingly and rapidly, to keep the error minimal.

III. PARTICLE SWARM OPTIMIZATION

The Particle Swarm Optimization algorithm (abbreviated as PSO) is a novel population-based stochastic search algorithm. It is an alternative solution to the complex non-linear optimization problem. The technique is stylized representation of the movement of organisms in a bird flock or fish school. The PSO algorithm imitates from behavior of animals societies that don’t have any leader in their group or swarm. For instance, a group of animals that has no leaders will find their food by random. They generally follow one of the members of the group that has the nearby position with a food source (prospective solution). The flocks or groups achieve their best known condition simultaneously through contact between members who already have a better position. Animal which has a better condition will inform it to its flocks and the others will move simultaneously to that place. This process continues until the best conditions or a food source is discovered.

Kennedy and Eberhart introduced the Particle Swarm Optimization (PSO) in the mid 1990s and since then, it has been utilized as an optimization tool in various applications. The applications of this algorithm can be found in almost every field ranging from biological and medical applications to computer graphics and music composition. They considered the behavior of swarms of flocks in the nature and developed the PSO algorithm. This is a computational method that is used to optimize a problem by iteratively trying to improve particle position with regard to a given measure of quality. The particles are moved in the multi-dimensional search space and each particle of the swarm is a possible solution in the search space. The particles amend their positions, thus moving towards the global best (gbest) solution. PSO is not largely affected by the size and nonlinearity of the problem and can converge to the best possible solution in many problems where most analytical methods fail to converge.

The swarm or flock is typically modeled by particles in multidimensional search space. The swarm moves with a velocity and has a particular position. These particles flutter through hyperspace and have two important reckoning capabilities: the memory of their own best position and knowledge of the global or neighborhood’s best. The best simply means the position with the smallest objective value. All the members of the group notify the other members about the good positions and adjust their own position and velocity based on these good positions. So a particle has the following information to make a suitable change in its position and velocity:

i. A global best that is known to all and immediately updated when a new best position is found by any particle in the swarm.
ii. Neighborhood best that the particle obtains by communicating with a subset of the swarm.
iii. The local best, which is the best solution that the particle has seen.

At each time step, each of these particle positions is scored to obtain a fitness value based on how well it solves the problem. Using the local best position (lbest) and the global best position (gbest), the particle velocity update equations in the simplest form that govern the PSO are given by

$$v_i(k+1) = w * v_i(k) + c_1 r_1(\text{lbest} - x_i(k)) + c_2 r_2(\text{gbest} - x_i(k)) \quad (3)$$

where w, c_1 and c_2 are called the coefficient of inertia, cognitive and society, respectively. The r_1 and r_2 are uniformly distributed random numbers in [0, 1]. The term v_i is limited to the range ± vmax. If the velocity violates this limit, it will be set at its proper limit. Changing velocity enables every particle to search around its individual best position and global best position. Based on the updated velocities, each particle changes its position according to the following:

$$x_i(k+1) = x_i(k) + v_i(k+1) \quad (4)$$

Fitness function is given by following equation and the flow chart of the conventional PSO is shown in Fig. 1.3.

$$\text{fitness} = \sum_{n=1}^{N} [d(n) - y(n)]^2 \quad (5)$$

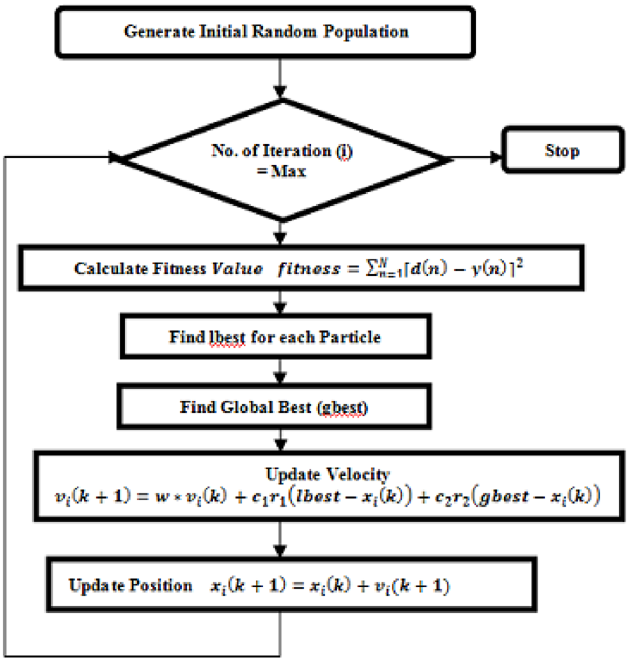

Fig. 3 Conventional PSO Flowchart

When every particle is updated, the fitness value of each particle is calculated again. If the fitness value of the new particle is higher than those of local best, then the local best will be replaced with the new particle. If the fitness value of the new particle is higher than those of global best, then the global best will be also replaced with the new particle. The algorithm repeats the above updating process step by step; the whole population evolves toward the optimum solution.

IV. RESULTS

Most chemical process systems are nonlinear in nature. Liquid level control system is an important control problem. For example, the control of liquefied petroleum gas in a conical storage tank is difficult; as the level decreases, the liquid vaporizes. The control of liquid level is a nonlinear problem. This is due to the relationship between the controlled variable (level) and the manipulated variable (flow rate), which has a square root relationship. Conical tanks find wide applications in process industries. Their shapes contribute to better dispersal of solids when mixing, providing more complete drainage, especially for viscous liquids. Control of conical tank is a challenging problem due to its constantly changing cross section. The process taken up for study is to control the level in a conical tank [2].

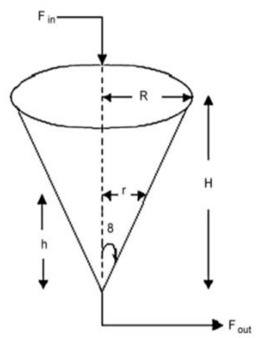

Fig. 4 Conical Tank Level Process

The conical tank system exhibits non-linear characteristics where the process or disturbance characteristics are changing continuously. Therefore the primary task of the controller is to maintain the process under stable conditions even at different kinds of disturbances.

Using the law of conservation of mass,

$$F_{in} - F_{out} = A\frac{dh}{dt} \quad \text{or} \quad F_{in} - F_{out} = \frac{dV}{dt} \quad (6)$$

where F_{in} is inflow rate of the tank cm3/s , F_{out} is the outflow rate of the tank cm^3/s, R is the top radius of the tank, H is the total height of the tank and r is the radius at any height h_i cm, A is the area of cross section and V is the Volume of the tank and is given by

$$V = 1/3\ \pi r^2 h \quad (7)$$

Applying the steady state values, and solving the eqns (6) and (7), for linearzing the non- linearity in the conical tank [2],

$$\frac{H(s)}{F1(s)} = \frac{R\tau}{\tau s + 1}$$

where $\tau = R_t A h_s^2$ and $R_t = \frac{2hs}{F2s}$

The transfer function describing the plant [2] is as follows:

$$G(s) = \frac{12\, e^{-2.05s}}{(53.6s+1)} \qquad (8)$$

The conical tank with the given transfer function has been used for the work. Step signal is used as an input and various controllers are used to find out the best performance of the system.

In the simulations using PSO algorithm, the number of iterations are varied and the population of the swarm is kept constant at 50. A comparative study of the performance of the initial global best position out of randomly initialized swarm particles to the performance of the final global best position is presented which comes after the application of "particle swarm optimization" algorithm. The performance specifications for the system are given in Table 1.

Number of Iterations	Global Best Position		Local Best Position	
	Minimum	Maximum	Minimum	Maximum
50	2.0499	2.1921	-3.1343	3.1868
60	2.0334	2.1847	1.3469	2.4141
70	2.0173	2.1706	-3.7900	3.5635
80	2.0945	2.1644	0.5222	2.3674
90	2.0093	2.1523	1.2010	2.3340
100	2.0237	2.1792	1.4800	2.2354
120	2.0014	2.1693	-1.1945	2.442
130	2.0252	2.1840	1.4647	2.4407

Fig.5 Comparison of Global and Local Best Position at Different Iteration Values

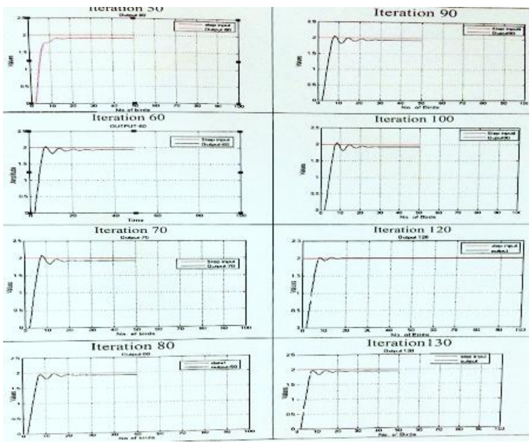

Fig.6 Simulation results of the system at different iterations

With regards to Fig. 6, it is evident that the PSO tuning method provides the best closed-loop performance. In case of PSO implementation we have varied the number of iterations that means the number of steps to be taken by the swarming particles in the search space. The results obtained indicate that as the number of iterations went on increasing the performance of the system also went on improving. The simulation results of the system are shown in fig. 6 and it is clear from the results that by varying the number of iterations we can improve the performance of the system. The best results are obtained when the value of iteration (n) is equal to 130 and the value of Kd = 1.9688, Ki = 0.0204 and Kp = 0.6300. The overshoot time, rise-time and settling time of the PSO based PID controller is 0.5, 1.8 and 12ms respectively, at iteration value equals to 130 is given by An analysis of the performance characteristics for all the control loops shows that the PSO method outperforms the tuning technique under consideration in this study.

V. CONCLUSION AND FUTURE SCOPE

In the present work, performance analysis of a conventional PID controller with that of intelligent controllers has been presented. Firstly, a simulation model of PID and PSO based PID controllers have been constructed with the help of MATLAB/ SIMULINK. It has been followed by performance analysis of a conventional PID controller with the intelligent controllers and investigating the results. The analysis of the time-response characteristics of the systems for a conventional PID and intelligent controllers show that PSO based PID controller performs significantly better than the conventional controllers. The effectiveness of the intelligent controllers and PID controller has been evaluated in terms of overshoot, settling-time and rise-Time.

According to the profiling results, the use of soft-computing techniques resulted in better dynamic and static characteristics. The response of the system is faster than in the case of conventional PID controller. The amount of overshoot for the output response is successfully decreased using the soft computing techniques. PSO enabled the PID controller to get an output which is robust and has faster response.

In case of PSO implementation we have varied the number of iterations that means the number of steps to be taken by the swarming particles in the search space. The results obtained indicate that as the number of iterations increases the performance of the system also improves. The analysis obtained out of the investigation results in all the cases, clearly establishes the fact that intelligent controllers are superior as compared to the conventional PID controller for the following reasons:

- PSO displays stochastic behavioral characteristics.
- It is a population based search technique with the ability to handle arbitrary non-linear cost functions and,
- PSO does not require gradient information of the objective function being optimized.

From the results presented in the study it was shown that the PSO tuning yielded improved responses and can be applied to conical tank process encountered in the process control industry.

Hybrid techniques such as Neuro-Fuzzy, Fuzzy-GA or PSO-Fuzzy can also be implemented for further extension of the work. Fractional order PID controllers may be used in place of conventional PID controllers in order to obtain superior results. Fractional order PID (FOPID) controllers can contribute significantly in this area.

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