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PID Controller Optimization using Artificial Fish Swarm Algorithm

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***Abstract*—Traditionally the PID controllers are being tuned by conventional trial and error method. A new intelligent method of PID tuning is used to tune the PID pressure control system. Using this method the overshoot of the system is very less with properly tuned PID parameters The research is also compared with other PID optimization approaches. The results found in the study shows that the optimization is valid and effective.**

***Keywords*—Optimization; PID; Pressure controller; Algorithm**

I. INTRODUCTION

A three term Proportional plus Integral plus Derivative (PID) controller, playing a vital role in the field of automation and control, has been counting as reliable component of industry because of its simplicity and satisfactory performance with vast range of processes. Because of its simple structure, it can be easily understood and implemented in practice. Thus their presence is highly appreciated in practical applications [1].

There are two methods of Tuning PID Controllers Conventional method and Intelligent Method. Conventionally the PID parameters are tuned by most commonly used Ziegler-Nichol method. These conventional tuning methods have some drawbacks like;

- Trial and Error Method i.e., much time consuming
- Produce quiet big overshoot
- High Cost
- Less Accurate

Therefore, recently many intelligent approaches are used [8]. In our study we are using Artificial Fish Swarm Algorithm to Optimize the PID Controller parameters (Kp, Ki, Kd).

Swarm Intelligence is a study of collective behavior of Reorganized system, usually set of species that communicate locally among themselves as well as with environment. There are many algorithms that use swarm techniques. Some of them are listed blow

- Artificial fish swarm algorithm (AFSA)
- Ant colony optimization (ACO)
- Particle swarm optimization (PSO)
- Honeybees optimization (HBO)
- Collective intelligence (COIN)

AFSA has been used in various different applications like; Parameter estimation method [2], combinatorial optimization problems [3], Reactive power optimization of power system [4], Short-term load forecasting [5] etc.

II. ARTIFICIAL FISH SWARM ALGORITHM

AFSA is a new Algorithm that is based and follows the behavior of Swarm techniques and Artificial Intelligence. It is new method proposed based on the behaviors of Animals [8].

a. Priniciple of Algorithm

In the shallow waters, the fish has the ability to find the area in the water that is more nutritious, and naturally there is a big number of fish gathered at that part of the water. There for an Artificial Fish (AF) practice is proposed that replicate the behaviors like Searching, Swarming and Following [6].

(1) Searching Behavior

In the water the fish has the natural ability to find the area which is most filled with food. When that area is discovered the fish sense and travel towards that area [6].

(2) Swarming Behavior

In swarming process, the fish try to avoid congestion with other species and move along in the same direction as the fellow fish [6].

(3) Following Behavior

When a fish in a group of fish finds the food, the other companions will quickly follow each other and will find the food [6].

The food consistence in the water is the objective of AFSA, and the AF individual has the variable state to, and by all above activities the solution space can be searched [6]. In regard of food searching every fish (In our case AF) moves randomly so being a self-studying process it is an optimization of specific extremum, while the swarming and the following behaviors are processes of AF interaction to neighboring environment [6].

A behavior based of artificial fish is constructed and this model summarizes the self-state and behavioral model of artificial fish. The algorithm iterates once means the individual moves once.

b. Structure of Algorthim

Afore elaborating the comportments of Artificial Fish (AF), let's initiate some terms that are to be used throughout this study. The state of Artificial Fish (AF) Individual can be represented as a vector. For example $X=(x_1,x_2,\ldots,x_n)$, where $x_i(i=1,\ldots,n)$ denotes the current position of Fish, $f(X_i)$ represents the food concentration. $d(X_i\ ,X_j)$ is the distance between two artificial fishes. Visual and δ is the range of visibility and crowd factor of AF respectively.

(1) Searching

When area of food is detected the fish is moved towards the area where the quantity of the food is high. The current position was X_i, then the AF randomly searches for the new position X' in the range of its visibility.

$$X' = Xi + rand.\cdot Visual \qquad (1)$$

If $f(X')$ takes over $f(X_i)$ the position of the fish is updated.

$$X_i = X_i + \frac{X_i}{d(X_i, X')} \cdot rand \cdot Step \qquad (2)$$

Otherwise the AF arbitrarily selects further position based on its judgment of quantity of the food and updates the position of the food.

$$X_i = X_i + rand. \cdot Visual \qquad (3)$$

(2) Swarming

While swarming, fish has the natural ability to share the food and avoid any distraction causes in the way. It is defines as AF I searches for its other mate in visual range. The center between the fishes is defined as X_c. Again if $f(X_c)$ takes over $f(X_i)$ the position of X_i is again updated.

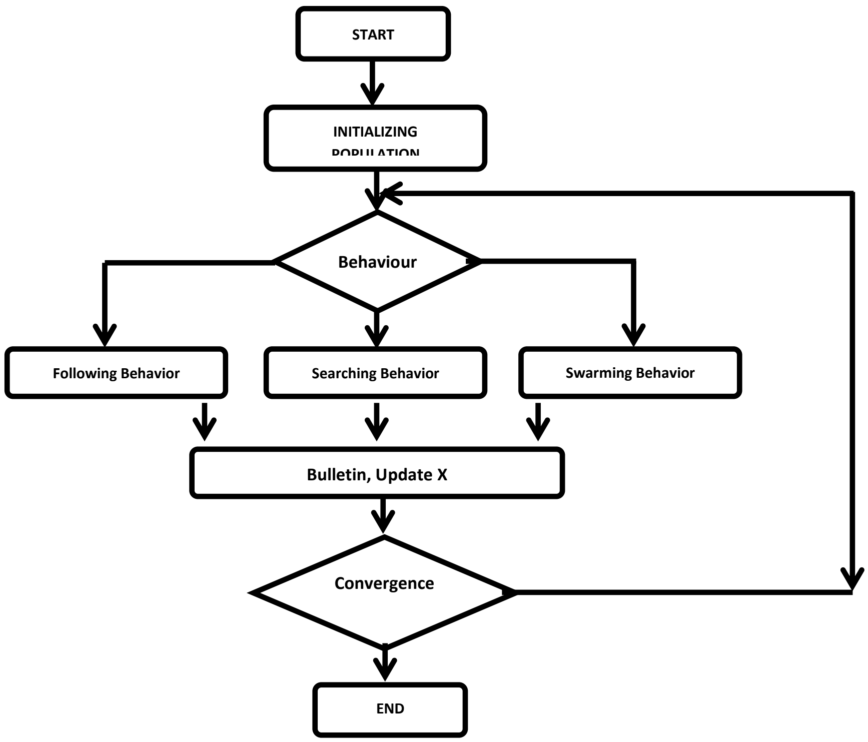

Figure 1: Flow of AFSA

$$X_i = X_i + \frac{X_c - X_i}{d(X_i, X_c)} \cdot rand \cdot Step \qquad (4)$$

(3) Following

When a single AF successfully finds the food, the other fish in the water has the natural ability to locate fish who has found the food. This act is defined as, AF I searches for its other mate in visual range. Compute $f(X)$ to get the maximum of this $f(X)$. The corresponding position is now X_c. If $f(X_m)$ takes over $f(X_i)$ the position of X_c is again updated.

$$X_i = X_i + \frac{X_m - X_i}{d(X_i, X_m)} \cdot rand \cdot Step \qquad (5)$$

III. OPTIMIZATION OF PID BY AFSA

The essence of ASFA optimization searching is the estimation of fitness function. And its design is directly proportional to the performance of ASFA. This study is aimed on the parameters K_p, K_i, K_d. to establish the objective function is a must to do for evaluation of performance index for searching optimization in a certain rule.

The gist for designing PID is making minimum system performance index function J. To assure the strength of system, gain margin and minimum phase condition are satisfied, to compare with literature [2]. Here in our study the ITAE is used as performance index.

$$J(ITAE) = \int_0^\infty t\,|e(t)|\,dt \quad (6)$$

$$J(ITAE) = DT^2 \sum_{k=1}^{LP} k\,|e(k)| \quad (7)$$

In this study the searching is aimed maximum, so the fitness functions is fixed accordingly. Hence the reciprocal of J(ITAE) is used as fitness function.

$$FC = 1/J(ITAE) \quad (8)$$

The steps of the algorithm are defined below with reference to Figure 1.

Step1: initiate the number of fish, the area of visibility, δ and enter any random position of AF, X=(x_1,x_2,…,x_n).

Step2: Calculate the food contamination of the defined position of AF. Obtain the concentration of food and updated position of Xi. The data must be saved in the bulletin box

Step3: for every AF, simulation reviews the results of swarming behavior and following behavior. The behavior is chosen by each AF towards higher concentration of food. The Searching behavior is by default behavior of the algorithm.

Step 4: calculate the food contamination of the all AF at initial position as well as at each updated position. And then again the data must be saved in the bulletin box.

Step5: if the iteration is equated to the limit. The optimal concentration of food and corresponding position is the output. Go to step 3 of the output is not desired.

IV. THE ANALYSIS & DISCUSSION

The plant that is being used for the analysis of this study is SIM305-GAMN-FF-BATCH PID Pressure control Pilot Plant.

Pressure is one of the important conditions to ensure chemical reactions occur at a desired rate. It is also closely related to process temperature and both are closely monitored by the plant operators to ensure safety in operation and maintaining Product Quality. Following is the block diagram of PID Control system in Figure 2.

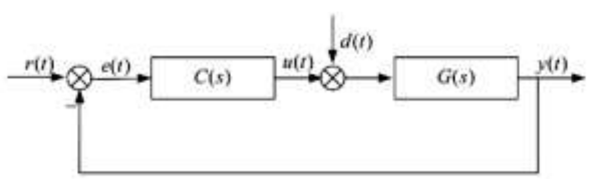

Figure 2: Block Diagram of PID Control System

Where,

$$u(t) = K_p\left[e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau + T_d\frac{de(t)}{dt}\right] \quad (9)$$

$$G(s) = \frac{e^{-11s}}{140s+1} \qquad (10)$$

Initially the Plant is tuned at the traditional Ziegler-Nichols method. The Parameters are found, Kp=8.19, Ki=26.208 and Kd= 3.943 with percent overshoot of 63. The system response is shown in figure 3.

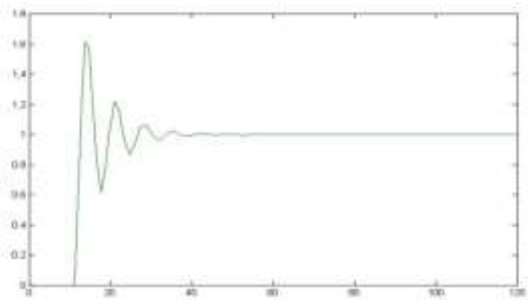

Figure 3: System response using Ziegler-Nichols method

Then the PID Controller Parameters are optimized using Artificial Fish Swarm Algorithm. The new parameters are estimated as, Kp=36.57, Ki=0.0022 and Kd= 7.849 with almost zero percent overshoot. The system response of the controller with new optimized parameters is shown in figure 4.

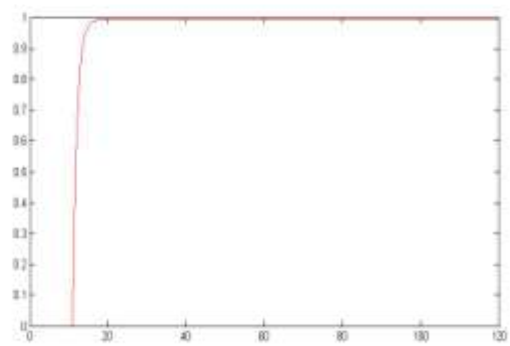

Figure 4: Step response controller using AFSA

Observing the Optimization of PID controller parameters of PID Pressure control plant, From Table I the AFSA showed very good performance. The study is compared with other Optimization method to validate and observe the mutual response of different optimization approaches. Figure 5 shows the response of different optimization methods

Observing the Optimization of PID Parameters using different approaches, Table 6 shows that the intelligent methods present very acceptable results over the conventional methods of PID Tuning. The traditional Zeigler-Nichols gives 63% of overshoot and requires some settling time. While Particle Swarm Optimization is also giving much acceptable results if it is compared with Zeigler-Nichols with the overshoot of only 15% and less settling time. This Study shows the Optimization of PID Parameters using Artificial Fish Swarm Algorithm gives very much accurate results if it is compared with both Ziegler-Nichols and Particle Swarm Optimization. The overshoot is almost equal to 0% and the settling time is really fast.

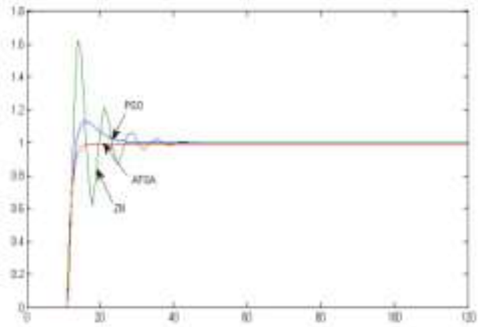

Figure 5: Step response of different optimization approaches

TABLE I
PARAMETERS AND PERFORMANCE OF DIFFERENT OPTIMIZATION APPROACHES

TYPE	Kp	Ki	Kd	%OS	Ts(s)
AFSA	36.57	0.0022	7.849	0	12.2
PSO	14.99	1772	13.872	15	22.1
ZN	8.1969	26.208	3.943	63	38.8

V. VALIDATION & OBSERVATION

The simulation results show the performance of the PID Parameters is much improved. For the validation of the study on the SIM305-GAMN-FF-BATCH PID Pressure control Pilot Plant the parameters are applied to see the controller response. The plant P&ID is shown in Figure 6.

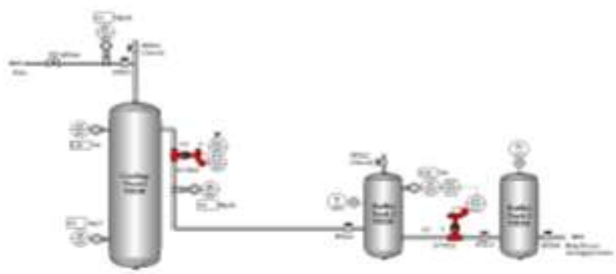

Figure 6: P&ID of SIM305-GAMN-FF-BATCH PID Pressure control Pilot Plant

Initially the plant parameters are tuned using Ziegler-Nichols PID tuning approach. As per in Table I, Kp=8.19, Ki=26.208, Kd=3.943 the response of controller is shown in Figure 7.

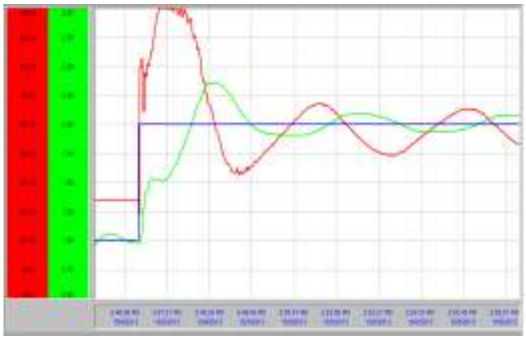

Figure 7: Step response of PID Pressure Control Plant tuned using Zeigler-Nichols Method

After the Plant is tuned using Zeigler-Nichols approach, for the validation of the study, the new tuned parameters as per in Table V, Kp=36.47, Ki=0.0022, Kd=7.849. Using these parameters the new trend of Controller response is shown in Figure 8.

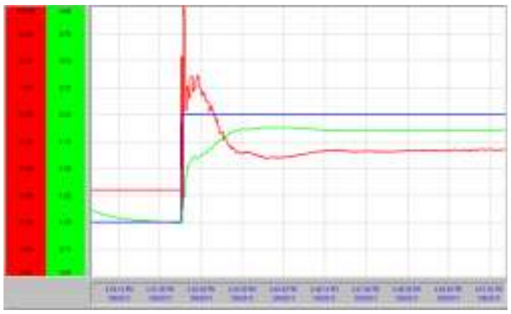

Figure 8: Step response of PID Pressure Control Plant tuned AFSA with offset

Since the response in Figure 8 using AFSA is not reaching to set-point**,** because the SIM305-GAMN-FF- BATCH PID Pressure control Pilot Plant allows only one digit after the decimal point. The integral gain i,e,. Ki=0.0022 is almost equal to zero, as integral part of PID controller improves the system offset [3]. Therefore the controller parameters need to be fine-tuned to reach to the maximum performance. The Controller is Fine-tuned to Kp=36.47, ki=5.65, Kd=7.8 the fine-tuned response of the controller is shown in Figure 9.

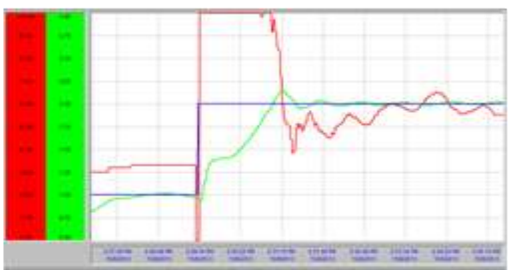

Figure 9: Step response of PID Pressure Control Plant after fine-tuning

For the industrial purposes the controller need to have a small overshoot for the better performance of the valve [3]. After fine-tuning of the controller, the system response is reaching its set-point with very less settling time as compared to the conventional method used in the industry.

VI. CONCLUSION

The PID parameters are tuned accordingly with Algorithm as stated in the Results section. The results are meeting the criteria and are acceptable. For the analysis and validation of algorithm PID Pressure Control Pilot Plant is used for the Optimization of the PID Parameters along with several other examples. The result is interpreted properly and the system response and performance is better when it is compared with other optimization methods. Overall the simulation results are satisfactory. And hence our objective of study that was to "tune the PID Control Parameters" is achieved.

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