A Genetic Algorithm (GA)-PID Controller for Temperature Control in Shell and Tube Heat Exchanger

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Abstract. In Genetic Algorithm tuned PID method for controls the fluid flow in the heat exchanger is presented in this paper. Shell and tube heat exchanger is the most generally utilized types of heat exchanger for heat transfer in many industrial purposes. The exchanger consists of mechanical part and controlling part. Both the modeled to ensure the efficient operation of shell and tube heat exchanger. The mechanical modeling is completely established on the type of applications. The controller only needs the input fluid and output fluid properties such as temperature and flow rate. Hence the primary objective of the paper is to focus on the controller part for enhancing the heat exchanger performance. This paper proposes the Genetic Algorithm tuned-PID controlling technique to make the settling time and overshoot of set point temperature to be less to a greater extent and the results are compared with the conventional PI method with various tuning algorithms [16]. The performance of proposed GA tuned plant has been compared with existing PID controller outputs with the help of MATLAB/Simulink.

Keywords: ANFIS Controller, BLDC Motor, Back EMF Method, Indirect Field Oriented Controller (FOC)

1. Introduction
Generally, the shell and tube heat exchangers with optimal design and control techniques are used in many industrial applications such as chemical, food and refrigeration industries [1]. In existing, fuzzy-PID has attracted most of the researchers because of its simple structure as well as PID has the advantage of high performance on steady state & fuzzy has the advantage of high performance on the dynamic state [11].GA is one of the methods influenced by nature that generally relies on the basic concept of fittest survival [12]. A detailed methodology for optimal tuning of PID controller has been proposed in this work. Suggested tuning of the operator using the genetic algorithm methodology. The existing method has some drawbacks such as less settling time and high peak overshoot. GA based PID technique has used but there are various mathematical operations are performed between the outputs coming from them. The optimal operation has to be chosen for the desired plant operations. In this paper, the general model of the controller has been developed for the shell and tube heat exchanger using transfer functions. The modeling is based on the flow rate of input fluid & flow rate of fluid coming into the shell, temperature sensor range, valve capacity to increase the flow rate and pressure. The GA-PID structure operation is implemented for obtaining the benefits such as less peak overshoot and settling time has been obtained for the desired set point.
2. Literature survey
Shell and tube are the two type’s structure of the heat exchanger. The tube structure belongs to the input fluid or process fluid which is to be heated and shell structure belongs to the fluid which will transfer the heat to the input fluid. The tube structures consist of tubes and shell structure [2]. It also comes under the mechanical part need more to modeling the tube structure and shell structure. The great process also a time of controller in the modeling processes. To understand the complete model of the heat exchanger first is difficult. In existing method was quite difficult to achieve the accurate model [3-5].

The nominal modeling of the heat exchanger should base on following condition such as, open loop condition and closed loop condition. In accordance with the set point is to maintain the output process fluid temperature by the controller. A flow rate of fluid coming to the shell structure and input fluid flow rate are the controlling parameter of the heat exchanger. Different control techniques are presented in practice. P, PI, and PID are the manually tuned controller and Fuzzy, ANFIS are the artificial intelligence controller. The typical PID controller has been attracted by many industries because of easy modeling, tuning of constants flexibility and controllability [6-8]. The constants are normally tuned by the following optimization methods such as Particle Swarm Optimization (PSO), Cuckoo Algorithm, Bat Algorithm, Genetic Algorithm, Ziegler–Nichols method. The other controller such as SMC and MPC has high benefits over dynamic control but it is quite complex to design and hard to implement [9]. Nowadays the combined structure of controllers has been designed. This method gives the nominal values of tuning constants with quick response and acceptableness of changing conditions. In spite of its advantages, it also has disadvantages such as optimization of tuning constants and it can be honorably used for the linear systems rather than the non-linear systems due to its low performance on non-linear systems [10]. The main aim of the design is to utilize both the benefits of the combined controllers.

3. Objective
- To design the shell and tube heat exchanger model in MATLAB/Simulink based on experimental data.
- To regulate the temperature of the heat exchanger output fluid through the implementation of GA based PID control scheme.

4. Proposed model of heat exchanger
The temperature sensor is used in the system to get the feedback from the input fluid coming out from the heat exchanger. The sensor is designed in the range of sensing the temperature 500-1500°C. The temperature signal is converted into the current signal by the transducer to the value of 4-20mA. The transfer function of the valve which is used to increase the flow rate of fluid coming into the shell is given by,

\[ G_{\text{valve}} = \frac{1}{3s+1} \times 0.75 \times 0.13 \]  

(1)

To control the temperature coming out of the tube outlet is controlled by the combined structure of Fuzzy-PID controller as well as feed forward controller is also added in this part to diminishes the error caused by the input fluid disturbance coming through the tube inlet. Figure 1 shows the general structure of the shell and tube heat exchanger. The general block diagram in figure.1 is included for easy understanding.
5. Function of Proposed Controller

5.1. PID Controller
The PID controller is one of the most traditional controllers used in the control systems of the industry because of its simplicity and ease of implementation. Even though it has a simple structure the tuning of gain value makes some difficulties in using them. In general, PID consists of three signals such as proportional, integral and derivative signals and they are added each other to generate error correction signal to the plant model. The gains of each signal are a proportional gain (Kd), integral gain (Ki), derivative gain (Kd). The input to the PID controller is error and output coming from the PID is error corrective value. The mathematical equation is given by,

$$PID_{output} = K_p \cdot \text{error} + K_i \cdot \int \text{error} \cdot dt + K_d \cdot \frac{d\text{error}}{dt}$$  \hspace{1cm} (2)

There are several tuning methods are experimented for tuning the PID gains. In that GA based PID tuning has been used in this paper because of its fast & adaptable gain process and non-complex structure [13]. GA method consists of following tuning methodology,

5.2. GA Algorithm
It is one of the methods used for optimization. The continuing performance improvement of computational systems has made them attractive for some types of optimization. The genetic algorithm begins with the stages of three evolutionary operators such as replication, fusion, and mutation to arrive at the best possible solution. General process chart of the GA is shown in figure 2.
5.3. GA based PID Controller

Compared to conventionally tuned PID regulator, GA tuned PID controller have much better output characteristic. The current tuning rule was used based on critical $K_c$ gain and critical per time. The integral $T_i$ time is set to infinity in this process, and the derivative $T_d$ time to zero. Using this to get the system's initial PID configuration. Using the steepest descent gradient process, this PID configuration will be further optimized. Only the proportional control action will be employed in this system. The $K_p$ will raise to a critical $K_c$ value at which the performance of the device will display repeated oscillations. The PID controller transfer function is given below

$$G_{feedback} = \frac{-18.461 s^2 - 6.769s - 0.205}{30s^2 + 31s + 1}$$

6. Simulation Results

The Simulation testing shown in figure. 3 has been done on the transfer function modeled shell and tube heat exchanger. The simulation run time is chosen as 400sec and the set point temperature is kept at 900C, input fluid gain is kept as 20 and $K_p$, $K_i$, $K_d$ values are kept as 13.25, 0.36, 56.25 respectively and the results have been obtained for the verification with conventional one using MATLAB/SIMULINK.
Figure 3. Simulink Diagram of the Proposed GA-PID controller

Figure 4 and 5 shows the input and output set point temperature. Fuzzy-PID controller output is shown in figure 6.

Figure 4. Input set point temperature

Figure 5. Output set point temperature

Figure 6. Fuzzy-PID controller output
The settling time and peak overshoot shown in figure 7 and figure 8 has been compared with conventional method [16]. The settling time of conventional method is 74 sec. The settling time of set point temperature using proposed controller is 65 sec.

![Figure 7](image1.png)

**Figure 7.** Settling time of set point temperature using proposed controller

![Figure 8](image2.png)

**Figure 8.** Peak Overshoot of set point temperature using proposed controller

The conventional peak overshoot is 3.54% but in proposed peak overshoot of set point temperature is 3.22%. The peak overshoot percentage is calculated as,

\[
\text{% peak overshoot} = \frac{92.9 - 90}{90} \times 100 = 3.22\%
\]

7. Conclusion

The Simulation has been done on the temperature control on the shell and tube heat exchanger model using Genetic-PID controller. The shell and tube heat exchanger controller part is modelled by the transfer function model. The Genetic-PID with feed forward controller is implemented to reduce the error caused by the input fluid. The genetic-PID which is the combined using multiplication operation has made peak overshoot and settling time of output set point temperature with the least values of 3.54% and 74 sec respectively. The values of peak overshoot and settling time obtained from the proposed control strategy which is less than the PI control method.

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