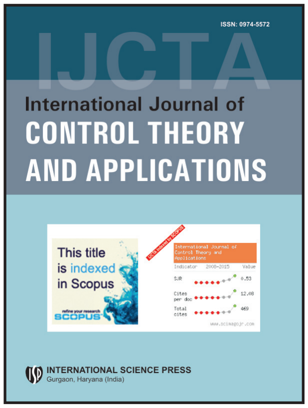

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A GA Approach for Optimum Design of Non-Linear PID Controller for Fluid Catalytic Cracking Unit

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Abstract: The Fluid Catalytic Cracking Unit plays an important role in the economy of modern refinery as it is used for value addition to refinery products. The implementation of control algorithms for such MIMO systems is often complicated due to continuous variations in process dynamics that occur because of change in operating point and the characteristics of nonlinear dynamic coupling. The model of FCCU that describes the dynamic behaviour of reactor and regenerator is developed by considering energy balance equations. Since the conventional PID is a linear controller, it is efficient only for a limited operating range in non-linear process. This paper reviews one of the non-linear PID methods using Genetic Algorithm (GA) techniques. The proposed approach had superior features, including easy implementation, stable convergence characteristic, and good computational efficiency. Simulation results are presented to show that the GA based NPID controller is capable of providing an improved closed loop performance over conventional controller parameter. GA based tuning method has proved their excellence in giving better results by improving the steady state characteristics and performance indices for NPID controller.

Keywords: FCCU, Genetic algorithm, PID/NPID controller.

1. INTRODUCTION

Fluid Catalytic Cracking unit is an important and widely used way to convert heavy feedstock into lighter, more valuable products. Various feedstock can be used, such as gas oils, vacuum gas oils or residual materials. Typical products are gasoline, light fuel oils and olefin-rich gases. Hot catalyst from the regenerator section flows in a fluidized state through the riser tube into the reactor. The incoming feed together with recycling slurry meet hot catalyst, start vaporizing and cracking in reactor. While the reactions take place, coke is formed on the catalyst.

The spent catalyst is separated from cracked material and being regenerated through burning off the coke. After regeneration, the catalyst is sent back to the reactor with a lot of heat absorbed in regeneration phase. The cracked hydrocarbons enter a fractionating tower, where it is separated into gas, light cycle oil, heavy cycle oil and slurry. The gasoline product has good overall octane characteristics suitable to be used for gasoline blending.

A controller is designed using MATLAB, for the real time FCCU plant to control the reactor and regenerator temperature. The simulations of Genetic Algorithm (GA) for the analysis of the parameter values of the controller are carried out and the interaction in the process is analyzed.

2. MODELING OF FCCU PROCESS

A typical FCC unit and its control flow diagram is shown in Figure 1. Feed stock arrives at the bottom of riser, vaporizes and cracks into products and the cracked products go to a fractionating system for separation into gasoline, light gases etc, carbon is burned off the spent catalyst in the regenerator i.e. catalyst deactivation and the regenerated catalyst i.e. fresh catalyst returns to the reactor carrying sufficient heat to supply the heat requirements of the endothermic cracking reaction, thus repeats the cracking cycle. In the presence of catalyst, the cracking is accelerated thousands of times and takes place at low temperatures than thermal cracking, which are advantages economically. The operating temperature of the reactor is about 776K – 820K and regenerator is about 998K – 1080K. The modelling of complex chemical systems for the simulation of process dynamics and control has been motivated by the important economics incentives for the improvement of plant operation and design.

A number of simplified assumptions have been made in order to formulate energy balance in reactor and regenerator which include:

1. Neglecting the conduction, convection, and radiated terms.
2. Heat of reaction and heat of combustion are constant.

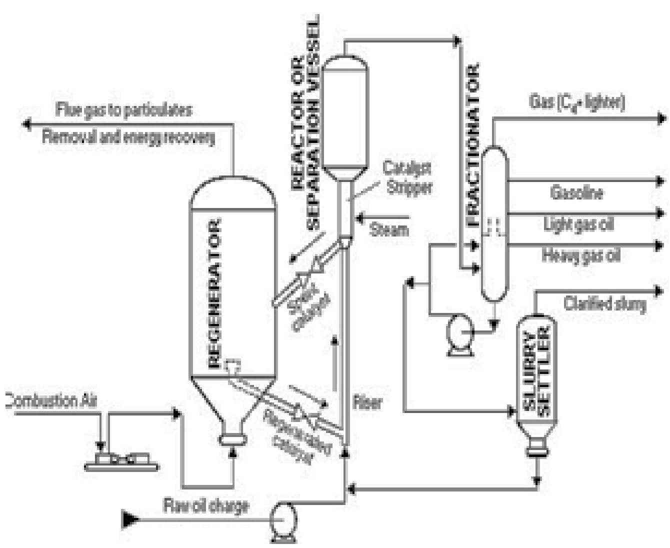

Figure 1: General setup of fluid catalytic cracking unit

3. REACTOR AND REGENERATOR MODELLING

3.1. Reactor Model

The residence time of feed in the riser is only a few seconds, and hence ideal reactor model is used. The energy balance around the reactor will be, Input stream – [Output stream-Heat of reaction] = Rate of Accumulation

Heat of Reg. catalyst + Heat of Feed + Heat of Stream – {Heat of Effluent – Heat of Spent Catalyst + Heat of Reaction} = Rate of Accumulation

3.2. Regenerator Model

The catalyst residence time in the regenerator is generally around 10 to 20 min. It is common to assume that the temperature and the amount of coke on catalyst are uniform throughout the regenerator.

Input stream – [Output stream + Heat of combustion] = Rate of Accumulation

Heat of Spent catalyst + Heat of Air – {Heat of Combustion – Heat of Reg. Catalyst – Heat of Flue gases} = Rate of Accumulation.

4. DESIGN OF NON-LINEAR PID CONTROLLER

Themain algorithm of the NPID controller is based on a nonlinear function as inherent part of the controller. The main goal is to achieve a desired response in the output of the plant, when the conventional PID couldn't achieve it. Therefore, the PID has been reconstructed using a non-linear function as follows:

$$u = K_p\varphi(e_p, \alpha_p, \delta_p) + K_i\varphi(e_i, \alpha_i, \delta_i) + K_d\varphi(e_d, \alpha_d, \delta_d)$$

where, $\varphi(e_p, \alpha_p, \delta_p)$ is the nonlinear function, $\varphi(e, \alpha, \delta) = \begin{cases} |e|^{\alpha}\ \text{sign}(e), \text{ when } |e| > \delta \\ \delta^{\alpha-1} e, \text{ when } |e| \le \delta \end{cases}$

K_p, K_i, K_d are the controller gains and they have the same meaning as the PID gains. Obviously, this controller has much more degrees of freedom (DOF) making it much designable but still more complex to tune.

By selecting $\alpha = 1$ and $\delta = 0$ will lead to the conventional PID form. Selection of different α of each gain, will lead to different behaviour of the controller. The α parameters are conventionally the error weighting. Since the motivation for designing such a controller is the demand for a better performance in the transient period and over steady state, the design of the parameters need to be focused on the desired response of the controller when error is around zero and when the error is larger than normal error. This behaviour is achieved by the parameters δ. This parameter defines the linear area in the nonlinear area.

The main considerations that should be taken in order to achieve more sensitivity to small errors of the proportional term αp should be larger than 1. In order to overcome the integral windup problem αi should be $-1 < \alpha i < 0$. This will reduce the integral action when the error is large, better performance could be achieved even if the model includes dead time. In order to overcome the noise perturbation over steady state αd should be larger than one.

5. GENETIC ALGORITHM

GA is based on an analogy with the genetic structure and behaviour of chromosomes within a population of individuals using the following foundations:

- Individuals in a population compete for resources and mates.
- Those individuals most successful in each 'competition' will produce more offspring than those individuals that perform poorly.

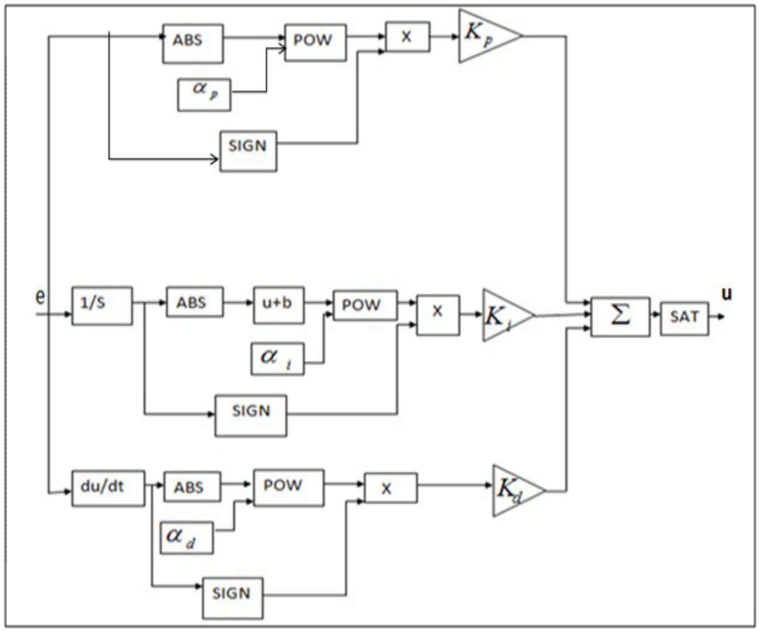

Figure 2: Basic NPID implementation

- Genes from 'good' individuals propagate throughout the population so that two good parents will sometimes produce offspring that are better than either parent.
- Thus, each successive generation will become more suited to their environment.

The GA maintains a population of n chromosomes (solutions) with associated fitness values. Parents are selected to mate, on the basis of their fitness, producing offspring via a reproductive plan. Consequently, highly fit solutions are given more opportunities to reproduce, so that offspring inherit characteristics from each parent. As parents mate and produce offspring, room must be made for the new arrivals since the population is kept at a static size.

Individuals in the population die and are Some of the commonly used genetic algorithm concepts include replaced by the new solutions, eventually creating a new generation once all mating opportunities in the old population have been exhausted. In this way, it is hoped that over successive generations better solutions will thrive while the least fit solutions die out.

New generations of solutions are produced containing, on average, more good genes than a typical solution in a previous generation. Each successive generation will contain more good 'partial solutions' than previous generations. Eventually, once the population has converged and is not producing offspring noticeably different from those in previous generations, the algorithm itself is said to have converged to a set of solutions to the problem at hand.

Some of the commonly used genetic algorithm concepts include initialization, selection, cross over, mutation, termination, genetic operators and elitism. These are used to produce the best offspring from the existing parents. In technical terms, we arrive at the optimum solution.

5.1. The Sequence of Genetic Algorithm

Genetic algorithm is then, slowly developed by defining the parameters and by using the method of natural selection and non-uniform mutation. The cross-rate, mutation rate and the population size is well defined. The range of values for the selection of K_p, K_i and K_d is mentioned and the corresponding program is linked with block diagram of the experimental setup. The program is run and the optimized values of K_p, K_i and K_d is obtained. We also observe the ISE graph characteristics. The graph flattens out at the end, indicating the arrival of optimized value.

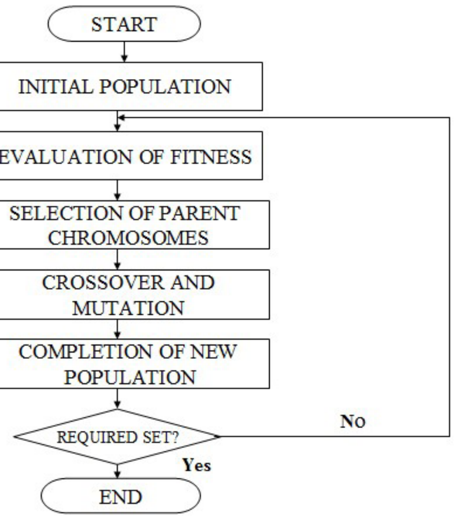

Figure 3: Flow chart of Genetic Algorithm

The optimized values are noted down and used to run tests such as servo regulatory, noise disturbance tests. The stability of the system with the optimum values is tested.

6. THE CLOSED LOOP RESPONSE OF FCCU

The simulink block diagram in Figure 4 is used for the tuning of controller parameters in closed loop.

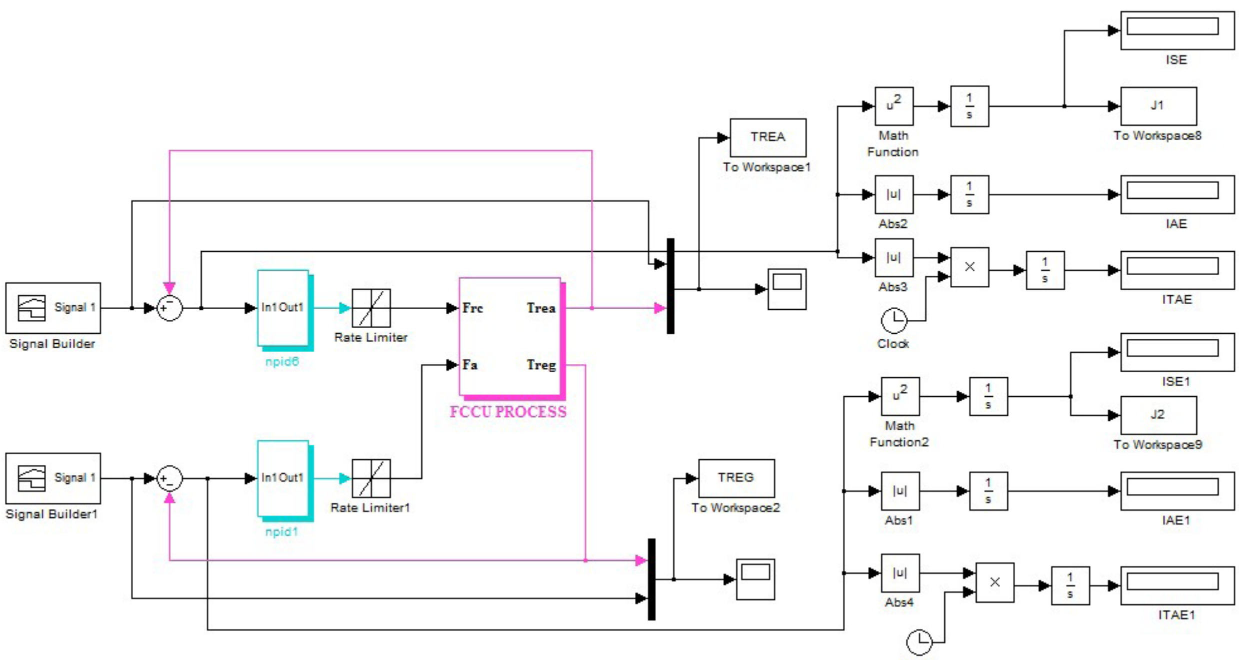

Figure 4: Closed loop tuning of FCCU

The closed loop system determines the optimum tuning parameters for the FCCU. It is tuned using genetic algorithm by generating new populations for 100 generations. The ISE graph is shown below and it represents an optimized value soon after 30 generations.

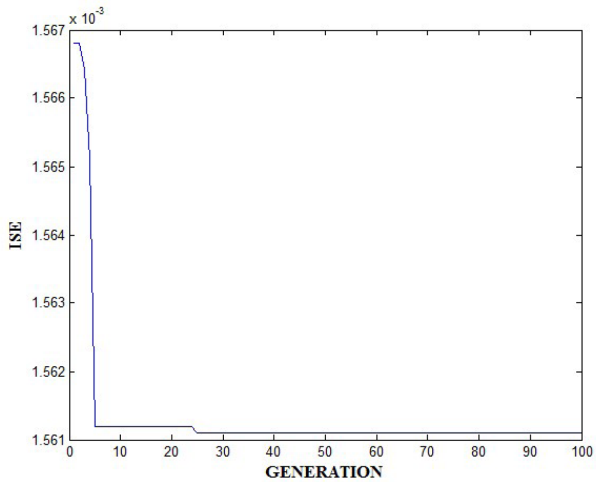

Figure 5: ISE graph for GA tuned NPID for 100 generations

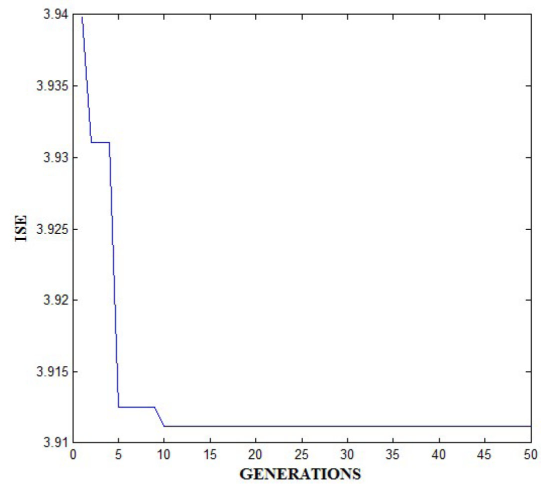

Figure 6: ISE graph for GA tuned PID for 50 generations

Table 1
Comparison of performance indices for GA tuned PID and GA tuned NPID controller

Control Variable	*GA tuned PID*			*GA tuned NPID*		
	ISE	*IAE*	*ITAE*	*ISE*	*IAE*	*ITAE*
Reactor Temperature	1.42 e+05	1791	3.057 e+05	1.30 e+05	1160	1.18 e+05
Regenerator Temperature	2.08 e+05	3134	1.53 e+06	1.01 e+05	2180	1.264 e+05

Table 1 shows the comparison of performance criteria for the two controllers. It is observed that the GA tuned NPID gives better performance than the PID control strategy in closed loop response.

7. SERVO RESPONSE OF GA TUNED PID & NPID CONTROLLERS

Simulation studies are carried out to demonstrate the tracking capability of GA tuned PID controller. The performance of FCCU for GA tuned NPID is shown in Figure 7 and Figure 8. The performance of FCCU for GA tuned PID is given in Figure 9 and Figure 10. From the response, it is observed that the reactor and regenerator temperature follow the given set points (Servo response).

Table 2
Comparison of performance indices for GA tuned PID and GA tuned NPID controller for servo response

Control Variable	*GA tuned PID*			*GA tuned NPID*		
	ISE	*IAE*	*ITAE*	*ISE*	*IAE*	*ITAE*
Reactor Temperature	2.36 e+05	4280	6.51 e+05	1.232e+05	1662	2.727 e+05
Regenerator Temperature	2.47 e+05	7013	1.51 e+06	1.016e+05	6830	1.462 e+06

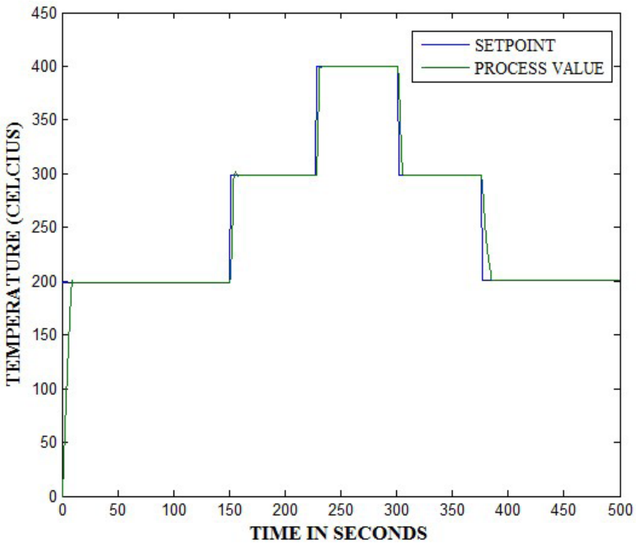

Figure 7: Servo response of reactor temperature of GA tuned NPID controller

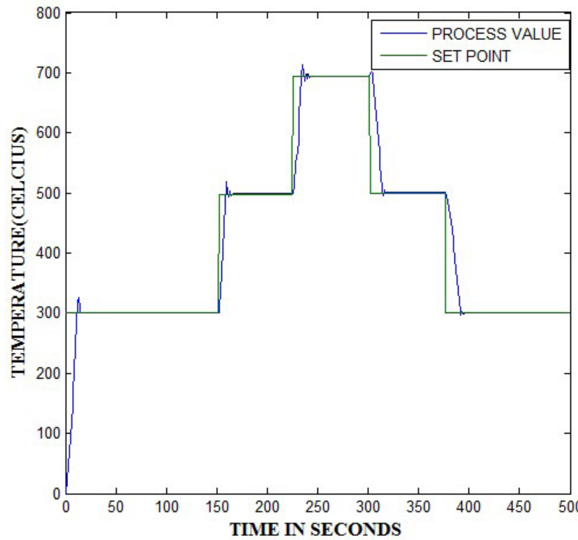

Figure 8: Servo response of regenerator temperature of GA tuned NPID controller

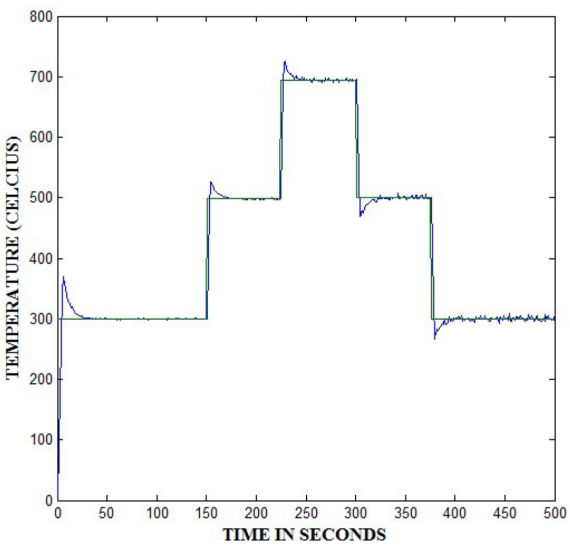

Figure 9: Servo response of reactor temperature of GA tuned PID controller

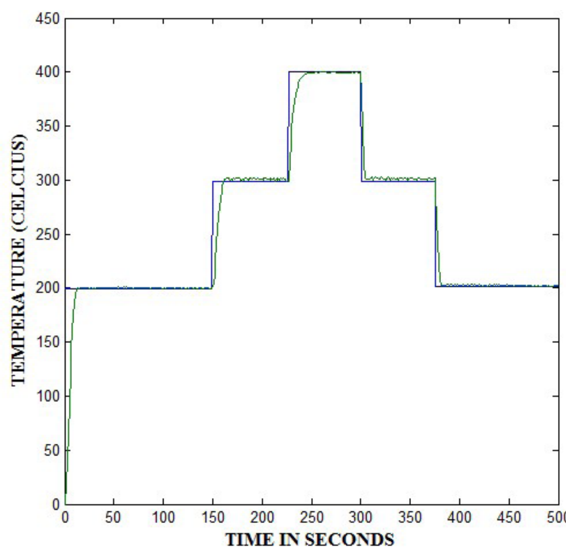

Figure 10: Servo response of regenerator temperature of GA tuned PID controller

Table 2 shows the comparison of other performance criteria for the two controllers. It is observed that the GA tuned NPID gives better performance than the PID control strategy in servo response.

8. SERVO REGULATORY RESPONSE OF GA TUNED PID & NPID CONTROLLERS

Simulation studies have been carried out to show the disturbance rejection capability of GA tuned PID & NPID controller with changing set points.

A step disturbance of 250 kg/sec is introduced to Fa and a disturbance of 150 kg/sec is introduced to Frc at 170 Seconds and removed at 320 seconds. The servo with regulatory responses of GA tuned NPID controller is shown in figure 12, figure 13 and the responses for GA tuned PID is shown in Figure 13 and Figure 14.

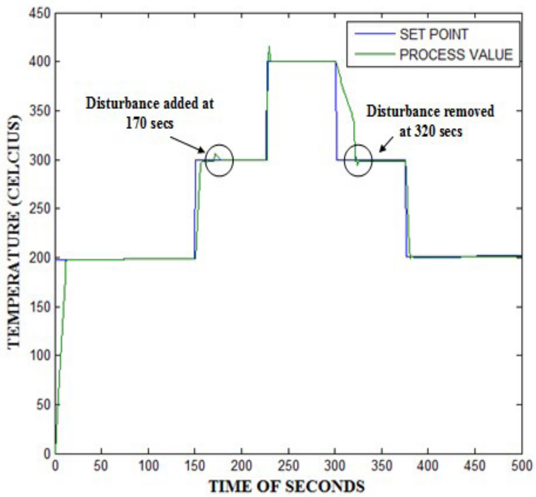

Figure 13: Servo with regulatory response of reactor temperature of GA tuned PID controller

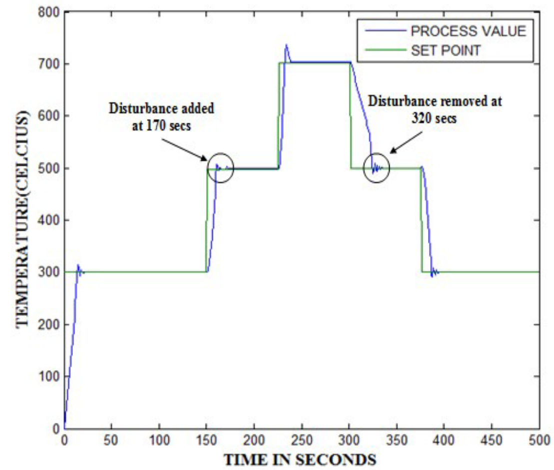

Figure 14: Servo with regulatory response of regenerator temperature of GA tuned PID controller

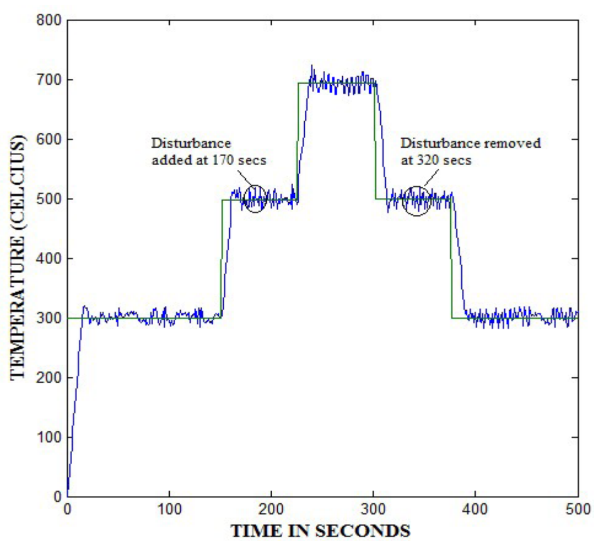

Figure 11: Servo with regulatory response of reactor temperature of GA tuned NPID controller

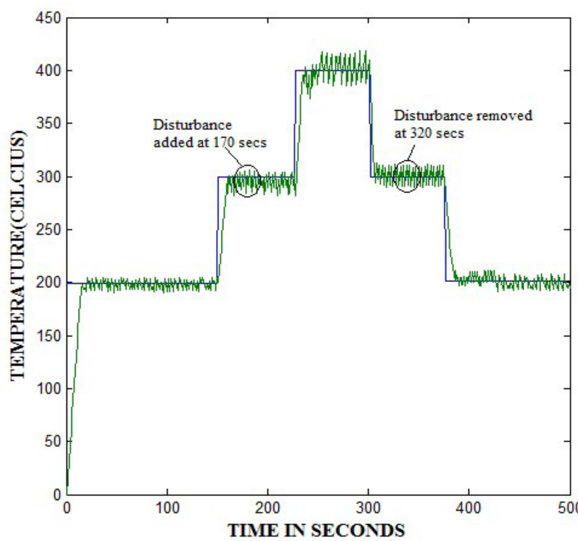

Figure 12: Servo with regulatory response of regenerator temperature of GA tuned NPID controller

Table 3
Comparison of performance indices for GA tuned PID and GA tuned NPID controller for servo regulatory response

Control Variable	*GA tuned PID*			*GA tuned NPID*		
	ISE	*IAE*	*ITAE*	*ISE*	*IAE*	*ITAE*
Reactor Temperature	2.87 e+05	4718	8.68 e+05	1.232e+05	1662	2.727 e+05
Regenerator Temperature	1.16 e+06	9449	2.03 e+06	1.016e+05	6830	1.462 e+06

9. NOISY MODEL RESPONSE OF FCCU

In order to study the stability of the NPID controller and its noise rejection, a white Gaussian noise with variance of 40 has been added to the system model.

This response deals with the inclusion of a disturbance introduced at 170 seconds and the same is removed at 320 seconds. The variance of Gaussian noise is about 40. The output is tracked for the given inputs of the process. The simulation shows that NPID is much stable with the presence of noise such as PID & It is seen that the performance criteria is under control which is tabulated in Table 4.

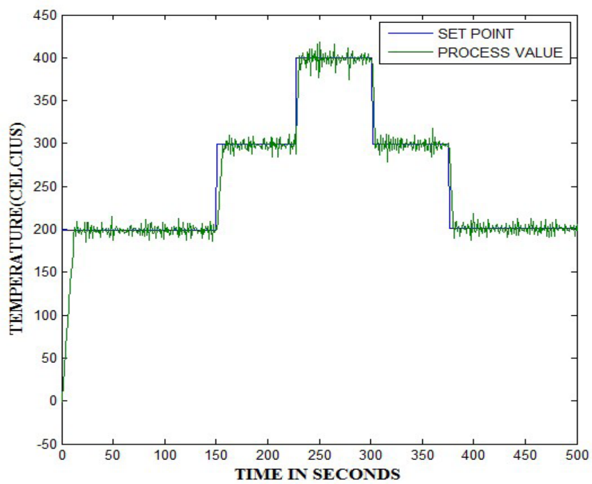

Figure 15: Noisy model response of reactor temperature of GA tuned NPID

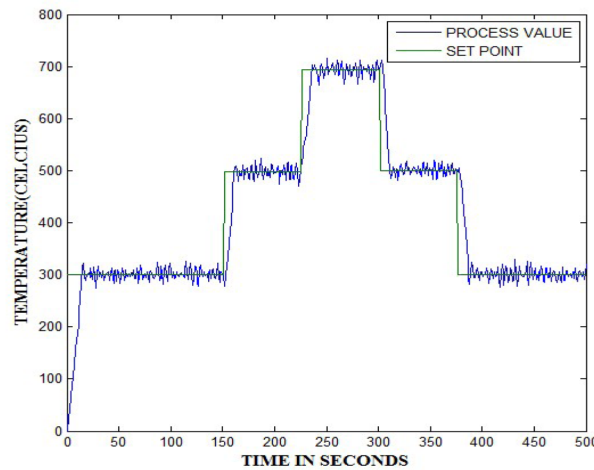

Figure 16: Noisy model response of regenerator temperature of GA tuned NPID

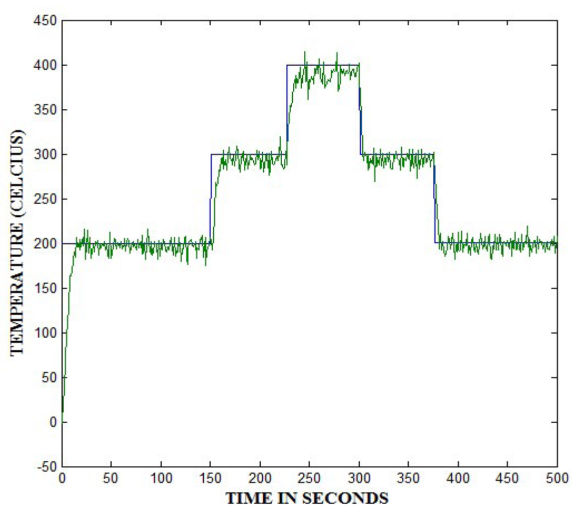

Figure 17: Noisy model response of reactor temperature of GA tuned PID

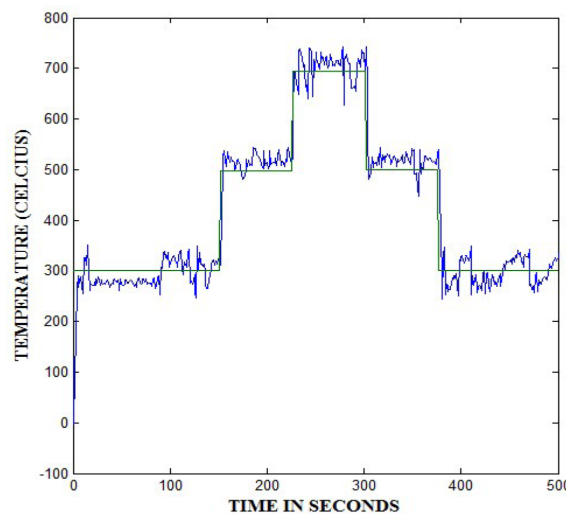

Figure 18: Noisy model response of regenerator temperature of GA tuned PID

Table 4
Comparison of performance indices for GA tuned PID and GA tuned NPID controller for noisy model response

Control Variable	*GA tuned PID*			*GA tuned NPID*		
	ISE	*IAE*	*ITAE*	*ISE*	*IAE*	*ITAE*
Reactor Temperature	2.38 e+05	5510	1.47 e+06	2.151 e+05	3974	7.38 e+05
Regenerator Temperature	3.39 e+06	1.29e+04	2.46 e+06	1.245 e+06	1.136 e+04	1.19 e+06

10. CONCLUSION

Mathematical model of FCCU for both reactor and regenerator has been derived using energy balancing equation. The simulink model of FCCU has been developed in MATLAB using real time steady state values of southern petroleum industry in Chennai. The open loop response of both reactor and regenerator were observed and the interaction effect has been studied. NPID based on nonlinear feedback has been designed and implement on the FCCU. Then the genetic algorithm for NPID controller was implemented and then optimized values were obtained.

It is observed that the performance criteria namely the ISE,IAE and ITAE settling time, undershoot and overshoot in servo and servo with regulatory response of GA tuned NPID controller is better than the PID controller.

Also from the responses, it has been observed that the proposed method has better tracking, faster settling, robustness to uncertainties and better control of noisy model.

11. FURTHER WORK

Still, further work needs to be done in order to increase noise rejection. According to simulation results, the current NPID controller seems to be as noise sensitive as PID. To achieve better noise rejection, the combination of NPID with TD (Tracking Differentiator) called ADRC (Active Distrubance Rejection Control) is suggested as future work. Stability analysis is also needed to be done as found in the previous sections.

REFERENCES

[1] Evelyn Lee and Frank R.G., “Mathematical model of the fluidised bed catalytic cracking plant”, *The society for computer simulation* 2(3): 219-236,1985.

[2] David R. Bully., “An overview of Genetic Algorithm”, *Department of Electrical and Electronic Engineering, University of Bristol,IEEE,*1993.

[3] Hany Ali, Rohani S., “Dynamic modeling and simulation of a riser-type fluid catalytic cracking unit”,*Chemical engineering & Technology*,20(2): 118-130.1997.

[4] X. Su, Dong Sun, B. Y. Duan ., “Design of an enhanced PID controller”, *Elseiver, Mechatronics*,15 1005-1024,2005.

[5] Guy Zaidner, Sammy Korotkin, Eli Shteimberg., “Non Linear PID and its application in Process Control”, *IEEE*,2010.

[6] RedahAlsabei., “Model based approach for the plant wide economic control of FCCU”, *Chemical Engineering*,2011.

[7] Reza Ssadeghbeigi., “Fluid Catalytic Cracking Handbook”, Second Edition.

[8] Megha Jaiswal., “Speed control of DC motor using GA based PID controller”, *IEEE*,2013.

[9] Chang-Bock Chung, In-su Han.,“Dynamic modeling and simulation of a fluidized catalytic cracking process”, *Part II: Property estimation and simulation, Chemical Engineering Science* 56(5):1973-1990.

[10] Stephanopoulos., “Chemical Process Control: an introduction to theory and practice”, 1984.

[11] Brien, R.T.O., Howe, J.M.,“Optimal PID design using standard optimal control techniques”,*American Control Conference*, 4733-4738,2008.