PLC BASED TEMPERATURE CONTROL USING PID CONTROLLER

A DISSERTATION

Submitted in partial fulfillment of the

requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

ELECTRICAL ENGINEERING

(With specialization in Instrumentation and Signal Processing)

By

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CANDIDATE'S DECLARATION

I hereby declare that this thesis report entitled **PLC BASED TEMPERATURE CONTROL USING PID CONTROLLER**, submitted to the Department of Electrical Engineering, Indian Institute of Technology, Roorkee, India, in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Electrical Engineering with specialization in Instrumentation and Signal Processing is an authentic record of the work carried out by me during the period June 2015 through May 2016, under the supervision of **Dr. R. S. ANAND, Department of Electrical Engineering, Indian Institute of Technology, Roorkee.** The matter presented in this thesis report has not been submitted by me for the award of any other degree of this institute or any other institutes.

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Place: Roorkee

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CERTIFICATE

This is to certify that the above statement made by the candidate is true to the best of my knowledge and belief.

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ABSTRACT

Temperature is a very important quantity, especially in the process industries all big plant like chemical plant, steel plant for them monitoring of temperature is very important. So temperature controller are needed to kept temperature stable. In this project heat exchanger system is used which is used to transfer heat from a hot fluid to a cooler fluid, so temperature control of outlet fluid is of prime importance. To control the temperature of outlet fluid of the shell and tube heat exchanger system a feedback conventional proportional-integral-derivative (PID) controller ,Feedback plus Feedforward and Internal Model Controller(IMC) are used. The designed controllers regulates the temperature of the outgoing fluid to a desired set point in the shortest possible time irrespective of load and process disturbances, equipment saturation and nonlinearity. A complete analysis using different kind of PID parameters Feedback plus Feedforward and Internal Model Controller(IMC),is presented in terms of system response. Performance of the controller is examined in terms of settling time, rise time and percent overshoot.

Acknowledgements

I would like to express my deep sense of gratitude and sincere thanks to my guide **Dr. R. S. ANAND**, Professor, Department of Electrical Engineering, Indian Institute of Technology Roorkee, for his valuable guidance and support. I am thankful to him for his persistent interest, constant encouragement, vigilant supervision and critical evaluation. His encouraging attitude has always been a source of inspiration for me. His helping nature, invaluable suggestions and scholastic guidance are culminated in the form of the present work.

I would also like to express my gratitude to my parents; their blessings, motivation and inspiration have always provided me with high mental support and contributed in all possible ways, in completion of this seminar report.

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Chapter 1

Introduction

In many areas of scientific research and production practice, the temperature is an important physical quantity need to measure and control. It is closely related to almost all of the physical and chemical processes and has great influence on the industrial production process and quality. Especially in areas of chemical, biological, machinery, precision instruments, measuring accurately and effectively controlling the temperature is the important conditions of high quality, low consumption and safety conduction. One such example is a control of water boiler reactor temperature using heat exchanger. The purpose of heat exchanger is to transfer heat from one fluid to another fluid, so temperature control of outlet fluid is of prime importance. To control the temperature of outlet fluid of the shell and tube heat exchanger system a conventional proportional-integral-derivative (PID) controller can be used. The system operates in a closed loop system to ensure the desired temperature will be obtained in fastest time and accurately. Conventional PID controller is widely used in process control industry due to its simplicity in structure and ease of implementation. PID measure the differences between the desire value and the actual value, by using the error calculated, it attempt to minimize it by adjusting the control input to obtain the desire output value. By tuning the 3 parameters in PID, the controller can provide specific control action designed for different requirements. In the field of metallurgy, chemistry, food industries and oil refining due to the time delay and process parameter uncertainty, the parameter of PID controller need automatic adjustment. PID controller exhibits high overshoots which is undesirable. To reduce the overshoot feed forward controller is used along with the feedback controller. The combined effect of feedback and feed forward control scheme gives a much better result than the feedback PID controller. Still the overshoot remains in a higher side. To further minimize the overshoot internal model controller is implemented.

1.1 Literature Survey

In 1999,Qing-Guo Wang,[5] Tong-Heng Lee gave a simple PID controller design method that gives the basic idea about the ziegler Nichols tuning method.

In 2010 Yuvraj Bhusan Khare,Subhransu Padhee,Yadhuvir Singh [3]proposed the idea to control the temperature of the outlet fluid of shell and tube type heat exchanger using conventional Internal Model based PID control and explained the advantage of temperature control importance in chemical industries.

Dr. Surekha Bhanot[6], et al.proposed the idea about the feedback, feed forward and cascade very well,also given the different control structures that can be implemented by own strategies and control valves ,I-P converter is also explained in her book ”Process control principles and applications”.

Dr. Yogesh V Hote, S Saxena [13],[10]proposed Internal Model Control modelling sceheme and design of IMC based PID controller, which gives the basic idea of understanding of IMC controller application and advantage of IMC controller over simple conventational PID controller.

T .Kuppan [9]explained types of heat exchanger in his book ,Heat exchanger design handbook,2000.Designing of heat exchanger,their types,installation, operation,maintainance and its application is well explained in his book which gives the clear idea of heat exchanger.

Dr.Zhao Kun-long[15], Wang Zai-ying also explained the advantage of IMC based PID controller over simple PID controller in his experiment of controlling boiler superheated steam pressure which also contribute understanding of IMC-PID controller scheme.

R D Kokate,L M Waghmare [16]gives IMC-PID and Predictive Controller Design For a Shell and Tube Heat Exchanger

In 2011, Reza Ezuan Samin, Lee Ming Jie, Mohd. Anwar Zawawi [1]presents the implementation of PID controller using Programmable Logic Controller (PLC) in heating tank of mini automation plant.

1.2 Objectives of Dissertation Work

The objectives of this dissertation work include:

1. Understanding of Temperature control in Industries.
2. Heat exchanger outlet fluid tempearture control.
3. Various control techniques like PID, Feedforward plus Feedback, IMC is implemented.
4. Comparision between performance of these controller .

1.3 Organisation of Report

This report is organized as follows: Chapter 2 describes the basic introduction about the system components. Chapter 3. In this we discuss about process description and in chapter 4 controllers are explained and there results are shown in chapter 5. Conclusions and scope for future work are stated in Chapter 6.

Chapter 2

Experimental Model Description

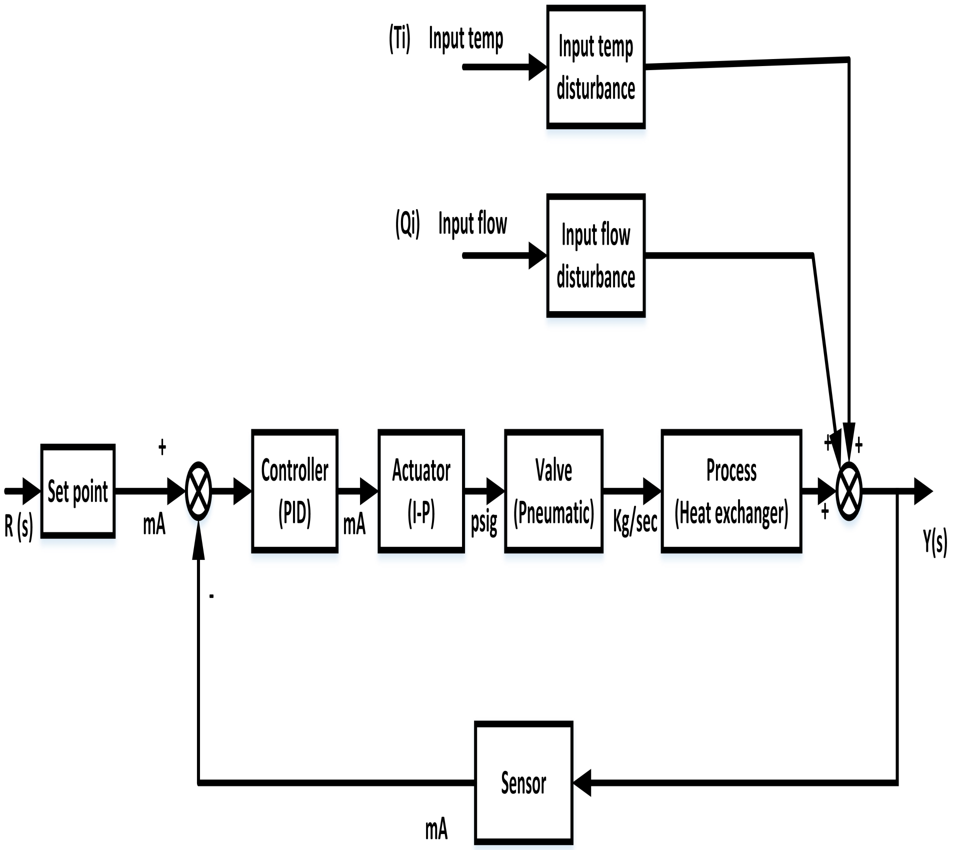

Figure 2.1: Basic block diagram of Experiment model

2.1 Heat Exchanger system

Property of Heat exchanger is to transfers heat between two fluids without mixing them up. The dynamics of heat exchanger depends on many factors like heat transfer area,temperature difference,flow patterns and flow rate of fluids, . Heat exchanger finds wide spread applications in different industries such as petrochemical,petroleum,,space craft, power generation, etc.

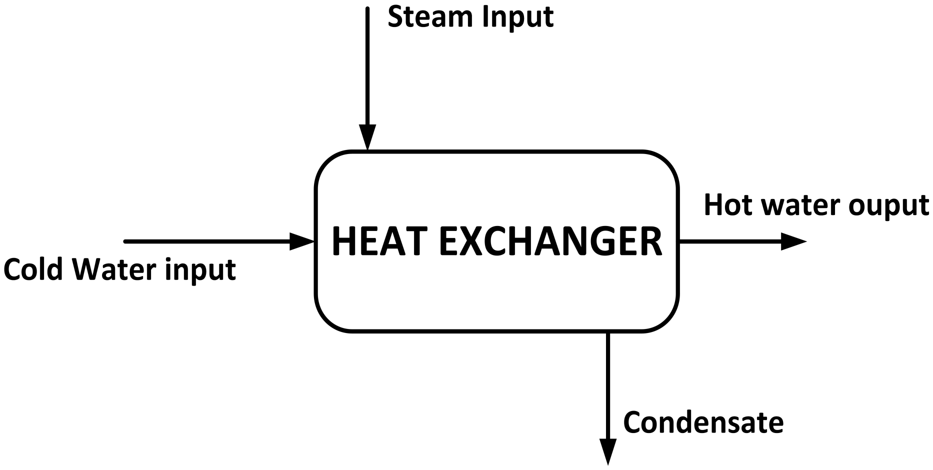

Figure 2.2: Principle of Heat Exchanger

There are several types of heat exchanger which are categorized with respect to transfer process,construction, flow and phase.Classification of heat exchanger is shown in

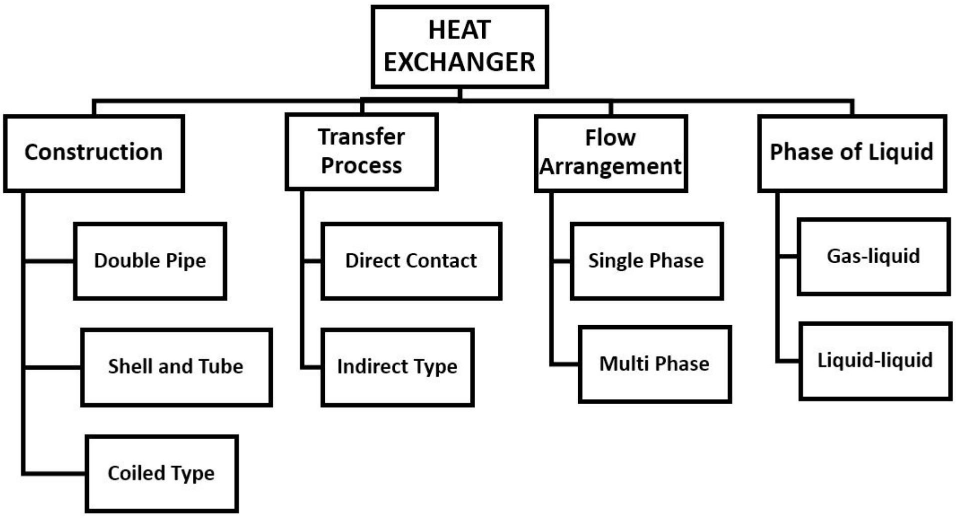

FIGURE 2.3: Classification of Heat Exchanger [9]

2.1.1 Shell and Tube Heat Exchanger

Oil refineries and large chemical processing plant employs shell and tube heat exchanger[4] as they are suited for higher pressure environment found in such plants. The exchanger structure consists of a shell with tubes bundled inside it. As the fluid flows through the tube and there is another fluid which flows over it, in the process there is heat exchange between them.

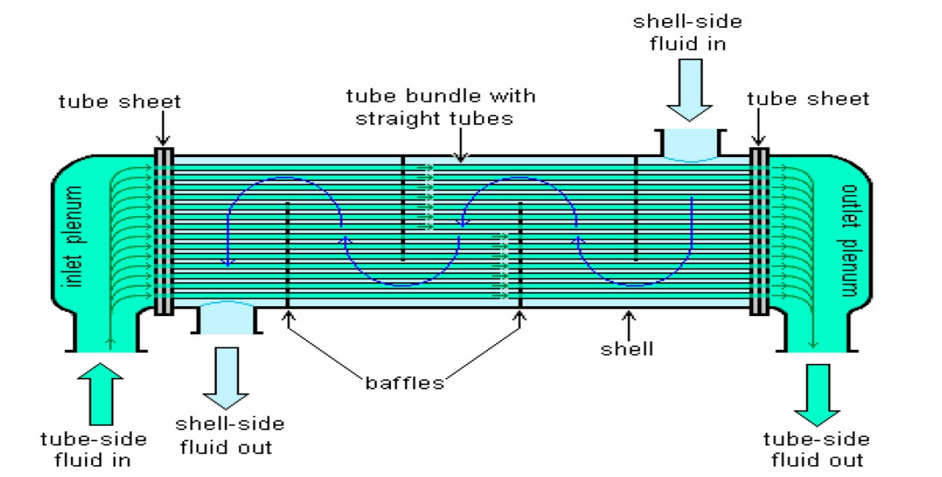

FIGURE 2.4: Shell and Tube type Heat Exchanger

Experimental Data of the heat exchanger

Different assumptions have been considered.

The first assumption is that the inflow and the outflow rate of fluid are same, so that the fluid level is maintained constant in the heat exchanger. The second assumption is the heat storage capacity of the insulating wall is negligible.

Exchanger response to the steam flow gain is $50°C/(kg/sec)$

Exchanger response to variation of process fluid flow gain is $1°C/(kg/sec)$

Exchanger response to variation of process temperature gain $3°C/°C$

Time constants 30 sec

$$Transfer\ function\ of\ process = \frac{50e^{-s}}{3s+1} \tag{2.1}$$

2.2 Temperature measurements techniques

There are several techniques to measure temperature like Bimetallic strips , RTDs Thermistors, for low temperature measurementand for measuring high range temperature the best suited method are ,infrared pyrometer , thermocouple, . Here we are considering thermocouple (which is linear and measure temperature in range of $500°C$) to measure the temperature of boilers or heating tanks

2.2.1 Thermocouple principle

A thermocouple [2] is a temperature-measuring device consisting of two dissimilar conductors connected in such a way that when the temperature of one junction differs from the reference temperature at the other jubction it produces a voltage (seebeck effect). Thermocouples are widely used for measurement and control of temperature in instustries.

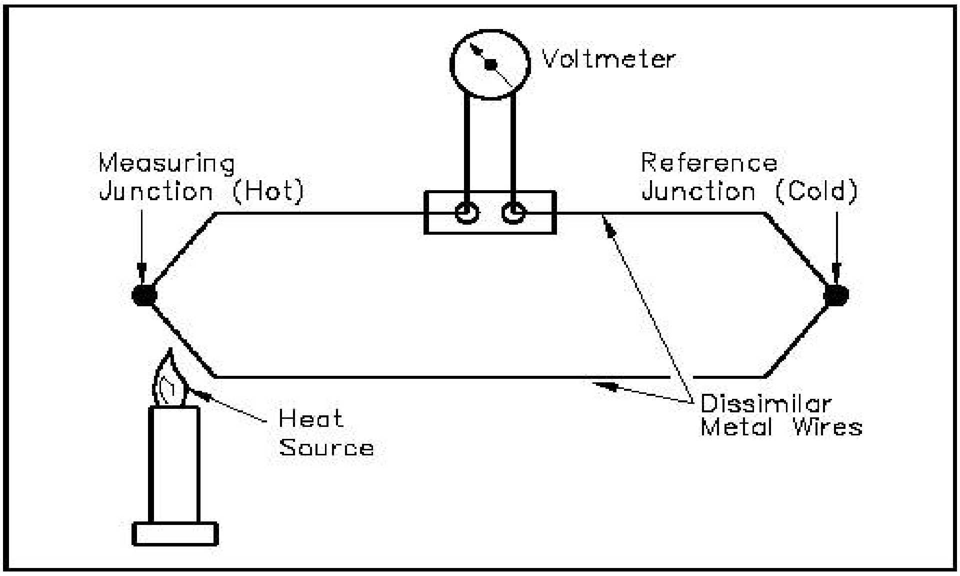

FIGURE 2.5: Thermocouple Principle [6]

TABLE 2.1: Types Of Thermocouples[6]

Type	Material	Temperature Range
R	87% platinium+13% rhodium-platinum	$0 - 1500°C$
S	90% platinium+10% rhodium-platinum	$0 - 1500°C$
K	Chromel-alumel	$-190°C$-$1300°C$
E	Chromel-constantan	$-100°C$-$1000°C$
J	Iron-constantan	$-200°C$-$800°C$
T	Copper-constantan	$-200°C$-$400°C$

The range of thermocouple $50°C$ to $400°C$

Time constant of thermocouple 10 sec

$$Transfer\ function\ of\ thermocouple = \frac{0.16}{10s+1} \tag{2.2}$$

2.3 Control valves

Control valve[6],[8] are final control element which are used in processto start , stop ,or regulate flow by a movable part that opens or close passage. Four main function of control valves are

- Start and stop flow
- Regulation of flow
- Regulation backflow
- Release of pressure

Opening or closing of valves are usually done automatically by pneumatic ,hydraulic or electrical actuators.

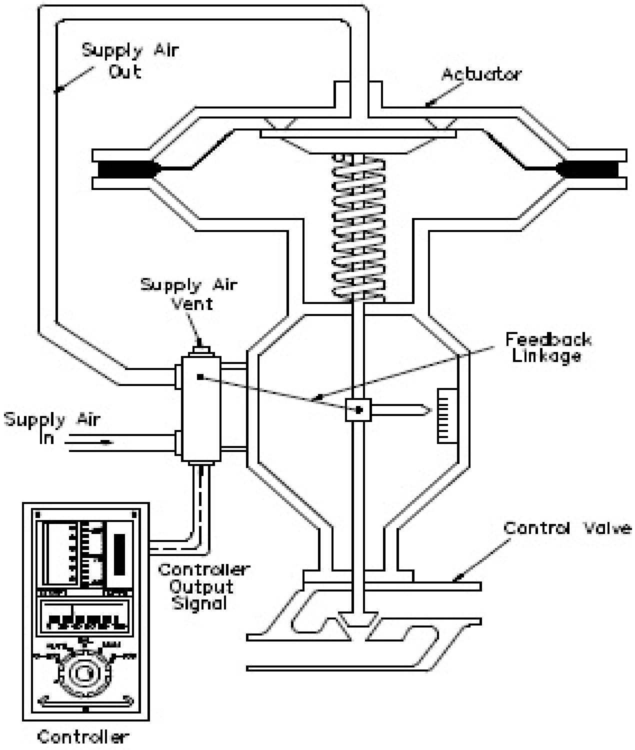

Figure 2.6: Line diagram of Control valve [6]

Here we are using pneumatic control values in my experiment. The amount of steam input flow(kg/sec) is controlled by the value by opening or closing of values depending on input pressure applied.

Control valve capacity 1.6 kg/sec for steam

Time constant of control valve 3 sec

Gain of valve 0.13

$$Transfer\ function\ of\ valve = \frac{0.13}{3s+1} \tag{2.3}$$

Chapter 3

Process Description

This chapter is entails a description of process . In chemical reactor storage tank are used for storing the process fluid. The a pump in association with a non-returning valve is use for supplying fluid to the shell and tube heat exchanger system. The fluid is heated in heat exchanger at a predefined set point . The steam at $180°C$,called super heated steam, is used for this purpose and it comes from the boiler. The steam flows through the tubes and at the same time the fluid flow through the shell of heat exchanger and in this manner gets heated up. For the purpose of sensing , in feed back path, thermocouple is used . The temperature of the heated process fluid is sensed using thermocouple. The output of thermocouple, which is a voltage , is fed to a transmitter , which in-turn converts it into a standard current signal of 4-20 mA. The set point temperature is compared with this and further given to a controller unit. The controller uses the control algorithm, to compare the output with the set point temperature. The final necessary command is given using the actuator unit. The actuator is an I-P converter which converts current signal (4-20 mA) into pressure signal (3-15 psig). The control valve is acted upon by this input thus controlling the flow of steam. Therefore, actuating the valve according to controller decision.

Exchanger response to variation of process fluid flow gain 1°C /(kg/sec)

Exchanger response to variation of process temperature gain 3°C/C

$$Transfer\ function\ of\ flow\ disturbance = \frac{1}{30s+1} \tag{3.1}$$

$$Transfer\ function\ of\ temperature\ disturbance = \frac{3}{30s+1} \tag{3.2}$$

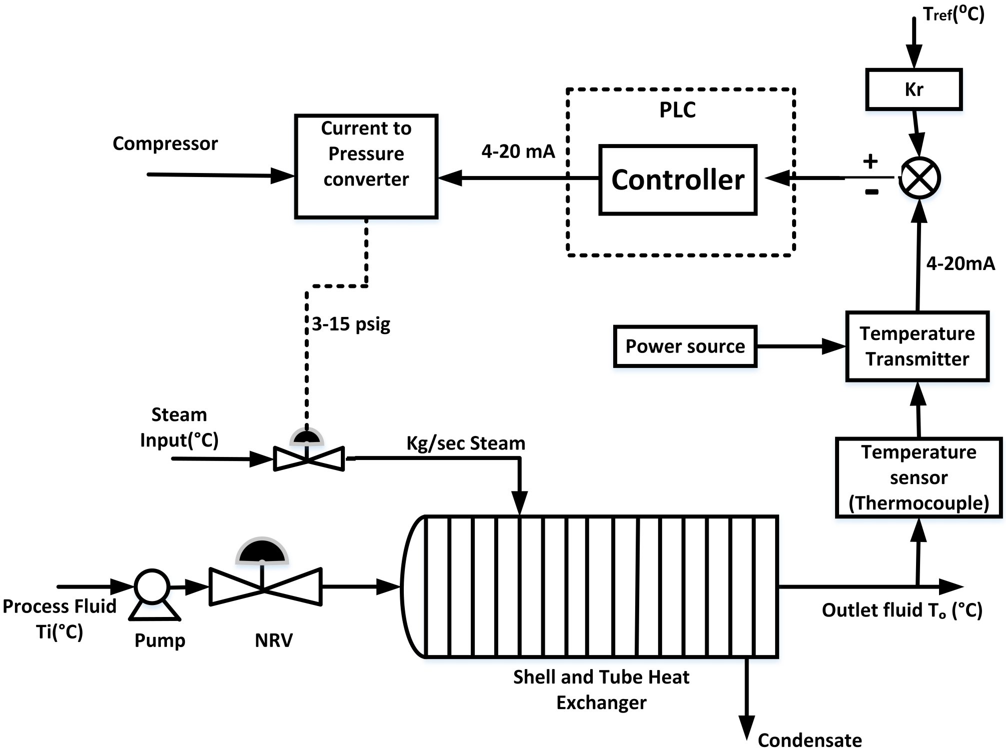

Figure 3.1: Schematic diagram of temperature control of heat exchanger

Chapter 4

Controllers

4.1 Feedback Controller

Whenver there is a disturbance or deflection, may be because of external or internal causes, the is output signal is compared with set reference. The error so generated is given to controller , which takes corrective measure so that desired output is obtained. Lets consider P, PI and PID controller for there responses :

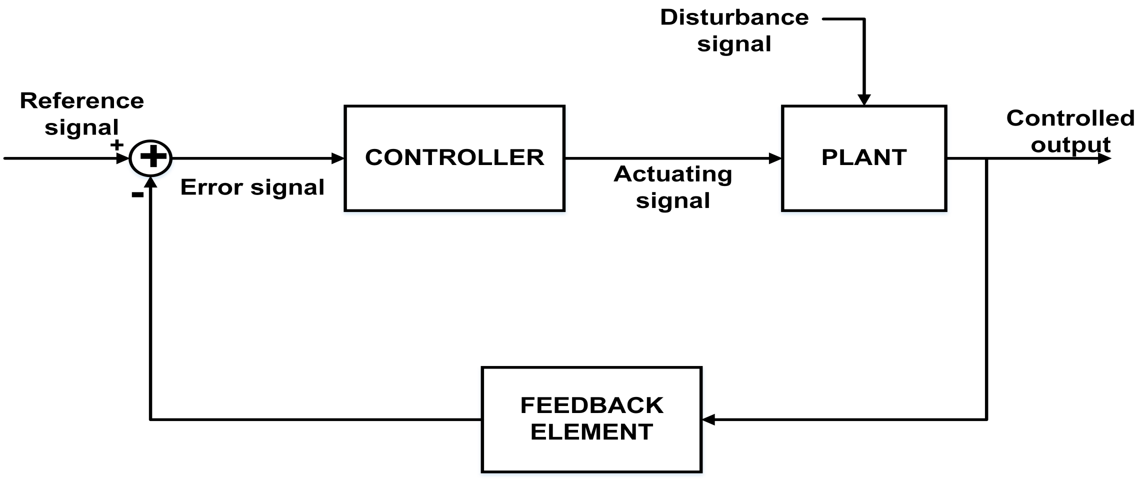

Figure 4.1: Feedback Controller

4.1.1 Proportional (P) Controller

The P controller is a part of feedback control system. It has more complexity than the simple on-off controller but way too simpler than the PID controller. Therefore, it can not stablise higher order system but works well with first order system. It works on the error through the changing controller gain K and changes closed loop dynamics. A larger value of controller gain results in control system with following:

- Minimum steady state error, i.e. reference is followed closely.
- Flow dynamics is regulated faster. This gives broader bandwidth to the closed loop system and larger sensitivity in relational to measuring noise.
- Amplitude and phase margin[11] are minimum.

4.1.2 Proportional Integral (PI) Controller

This is the most widely used controller particularly in industrial applications. PI controller eliminates steady state error and forced oscillations . But integral part may at times effect the overall stability. At the same time the speed of response is not improved. Therefore, in situations where speed of response is not a consideration PI is extensibly used . It has a simple structure, easy design and low cost. However, despite having such advantage it suffer under highly non-linear and uncertain environment to achieve desired performance.

4.1.3 Proportional Integral Derivative (PID) Controller

PID controller has all necessary ingredients for fast dynamic response: P mode for eliminating oscillations , I mode for forcing the steady state towards zero and D mode for fast reaction towards any change in input, this mode improves stability as well as response time by decreasing the integral time constant. PID is the most preferred controller option for process industry. For example pulp and paper industry has 98 percent of its controller as PID, in process industry 95 percent controller are PID.

$$G_c(s) = K_p + \frac{K_i}{s} + K_d s \tag{4.1}$$

4.1.3.1 PID tuning

Tuning is the act of obtaining optimum solutions for P, I and D gains. These are value obtained according to the system characteristics. Tuning methods are many , but most common methods are as follows:

Ziegler-Nichols Tuning : Ziegler-Nichols [12] Method is one of the most effective methods that increase the usage of P-I-D controllers, proposed by John G. Ziegler and Nathaniel B Nichols, in 1942 this popular method is based on frequency response analysis of frequency response analysis of process. It is also known as online tuning method or ultimate gain method. In this method placed the controller in the closed-loop with low gain; no reset and no derivative contribution i.e.K_i and K_d are set to zero. Then K_p value is increased until it creates a periodic oscillation at the output response. This critical K_p value is attained to be ultimate gain, K_c and the period where the oscillation occurs is named as Pc ultimate period. As a result, the whole process depends on two variables and the other control parameters are calculated according to the table 4.1:

TABLE 4.1: Tuning parameter according to Ziegler-Nichols [6] method

	P	T_i	T_d
P	$0.5K_c$	-	-
PI	$0.45K_c$	$P_c/1.2$	-
PID	$0.6K_c$	$P_c/2$	$P_c/8$

4.2 Feedback plus Feedforward Controller

The system performance is effected by the presence of disturbance . However, disturbance can be predicted and its effect can be mitigated .The feedforward controller eliminates the effect of disturbance before it changes the output. In conventional feedback system sensors are employed which detect the output of the process. The error is then fed to the controller which takes appropriate course of action. However , by the time control action reaches the process the output has already changed. Therefore , feed forward controller along with feedback controller is used . The feed forward controller used estimates the error and changes the effected variable before disturbance affects output. The cooperative action of both the controllers minimize the overshoot. Figure shows the transfer function to represent the system with feedback and feed-forward controller:

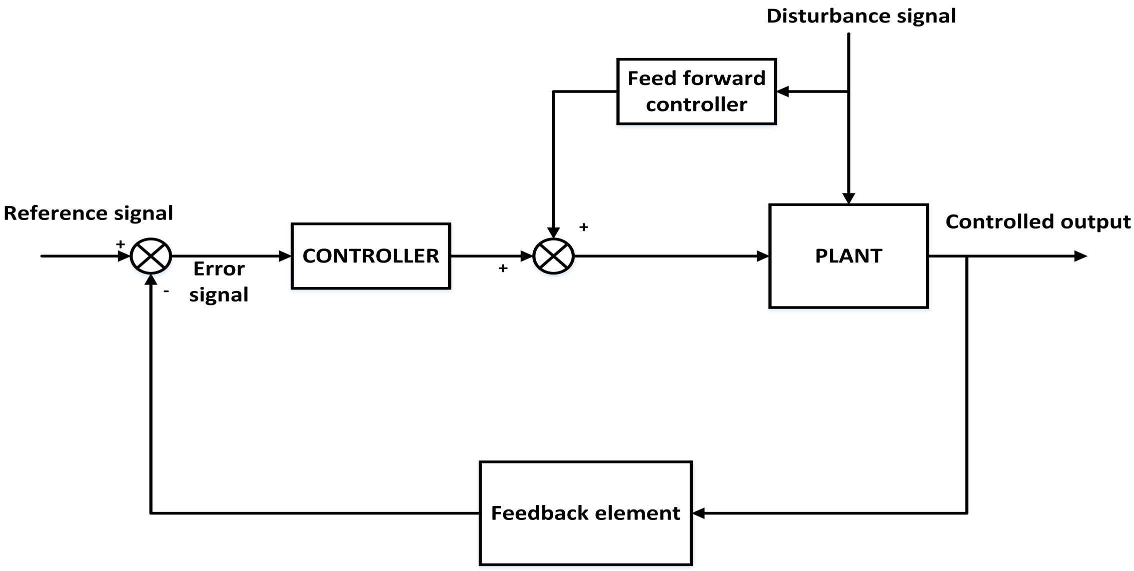

Figure 4.2: Feedback Plus Feedforward Controller

The transfer function of the feed-forward controller is

$$G_{ff}(s) = \frac{-G_d(s)}{G_p(s)} \tag{4.2}$$

$$G_p(s) = \frac{5e^{-s}}{90s^2 + 33s + 1} \tag{4.3}$$

$$G_d(s) = \frac{1}{30s + 1} \tag{4.4}$$

Here,G_d is transfer function of disturbance model.

G_p is transfer function of process model.

$$G_{ff}(s) = \frac{-18s^2 - 6.6s - 0.2}{(30s + 1)(\lambda s + 1)} \tag{4.5}$$

λ is filter tuning parameter .

4.3 Internal Model Controller

Internal model controller provides a transparent framework for control system design and tuning. The structure of internal model controller is shown in figure. The main feature of internal model controller is that the process model is in parallel with the actual process.

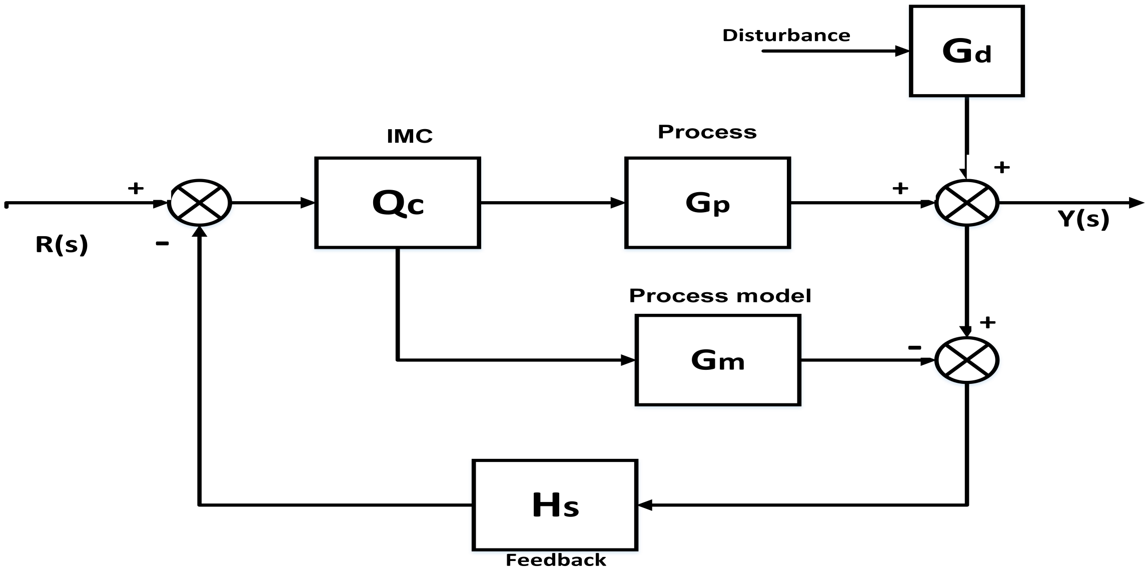

FIGURE 4.3: Internal Model Controller[10]

here,

$G_p(s)$ is Process transfer function.

G_m is Process Model transfer function

H_s is Feedback transfer function.

Q_c is primary controller(IMC).

The process model $G_m(s)$ is factored in to two parts, that is invertible part$G_{m-}(s)$ and non invertible part$G_{m+}(s)$, The non invertible part consists of RHP zeros and time delays. This factorization is performed so as to make the resulting internal model controller stable.

$$G_m(s) = \frac{5e^{-s}}{(30s+1)(3s+1)} \tag{4.6}$$

According to Pade approximation above equation is reduced to:

$$G_m(s) = \frac{5(-0.5s+1)}{(30s+1)(3s+1)(0.5s+1)} \tag{4.7}$$

Factoring model into Minimum phase and Non Minimum phase,such that is a $G_{m+}(s)$ non-minimum phase part and $G_{m-}(s)$ is a minimum phase.

$$G_m(s) = G_{m-}(s)G_{m+}(s) \tag{4.8}$$

$$G_{m-}(s) = \frac{5}{(30s+1)(3s+1)(0.5s+1)} \tag{4.9}$$

$$Q(s) = G_{m-}^{-1}(s)f(s) \tag{4.10}$$

f(s) is a low pass filter,commonly of the form

$$f(s) = \frac{1}{(\lambda s + 1)^n} \tag{4.11}$$

λ is tuning parameter,

n is an integer such that Q(s) become properfor physical realization.

$$Q(s) = \frac{(30s + 1)(3s + 1)(0.5s + 1)}{5(\lambda s + 1)^3} \tag{4.12}$$

Transient Characterstics

Rise Time: It is defined as "the time required for the response to rise from x% to y% of its final value", with 0%-100% rise time common for underdamped second order systems, 5%-95% for critically damped and 10%-90% for overdamped.

Settling Time: It is the time required for the response to reach and stay within the specified tolerance band (usually 2%-5%)of its final value.

Peak Time: It is the time required for the response to reach the peak of time response or the peak overshoot.

Peak Overshoot: It indicates the normalized difference between the peak and the steady state output and is defined as.

$$Peak\ percent\ overshoot = \frac{c(t_p) - c(t_\infty)}{c(t_\infty)} \times 100\% \tag{4.13}$$

Some of the parameters used to evaluate the performance of control loops are Integral square error, integral absolute error etc. In order to have a good closed-loop time response, these performance functions are considered during the design of a PID controller

$$Integral\ Absolute\ Error(IAE) = \int_0^\infty \left|e(t)\right| dt = \int_0^\infty \left|r(t) - y(t)\right| dt \tag{4.14}$$

$$Integral\ Square\ Error(ISE) = \int_0^\infty (e(t))^2 dt \tag{4.15}$$

Chapter 5

Simulation Results

The simulations for the different control mechanism discussed above were carried out in simulink and the simulation results have been obtained.The Simulink modelling of the shell and tube heat exchanger system with PID as a feedback controller,combination of feedback and feedforward and IMC are shown below.

5.1 Feedback controller

Simulation results of P,PI,PID controller are shown in figure .from the figure we can conclude PID controller is best than P and PI Controller because there are less overshoot,better rise time , settling time and offset error is zero but still there is one drawback we are not ale to reduce offset so we have taken feedback plus feedforward controller .

Applying Ziegler-Nichols tuning method we get.

The characteristic equation (1+G(s)*H(s) =0) in this case is obtained as below:

$$900s^3 + 420s^2 + 43s + 1.78K_c + 1 = 0 \tag{5.1}$$

Routh stability criterion gives Kc as 8.3.

Auxiliary equation

$$20s^2 + O.798K_c + 1 = 0 \tag{5.2}$$

Routh stability criterion gives Kc as 8.3. Gives w=0.13 and T=46.83 Therefore P=4.3 ,I=0.088 ,D=48.5 using Ziegler-Nichols Method

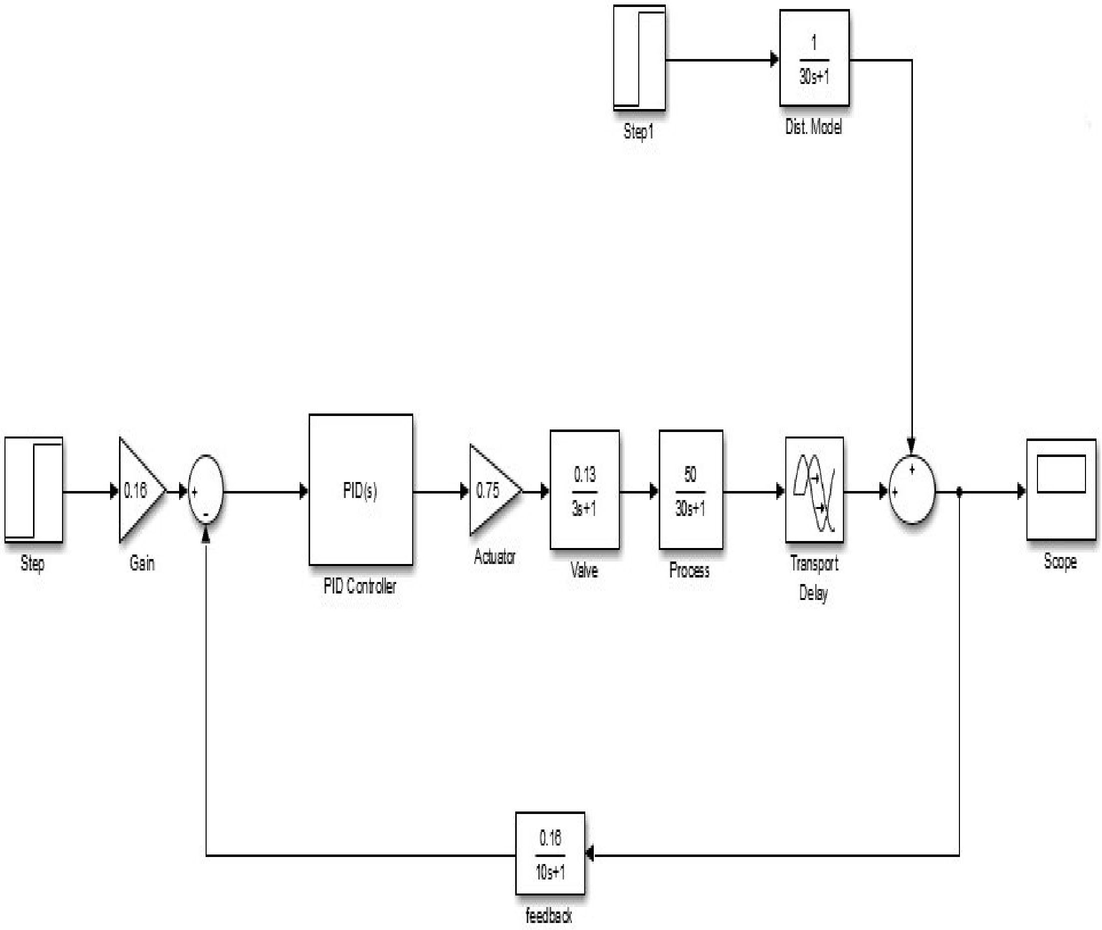

FIGURE 5.1: Simuink model of Feedback controller

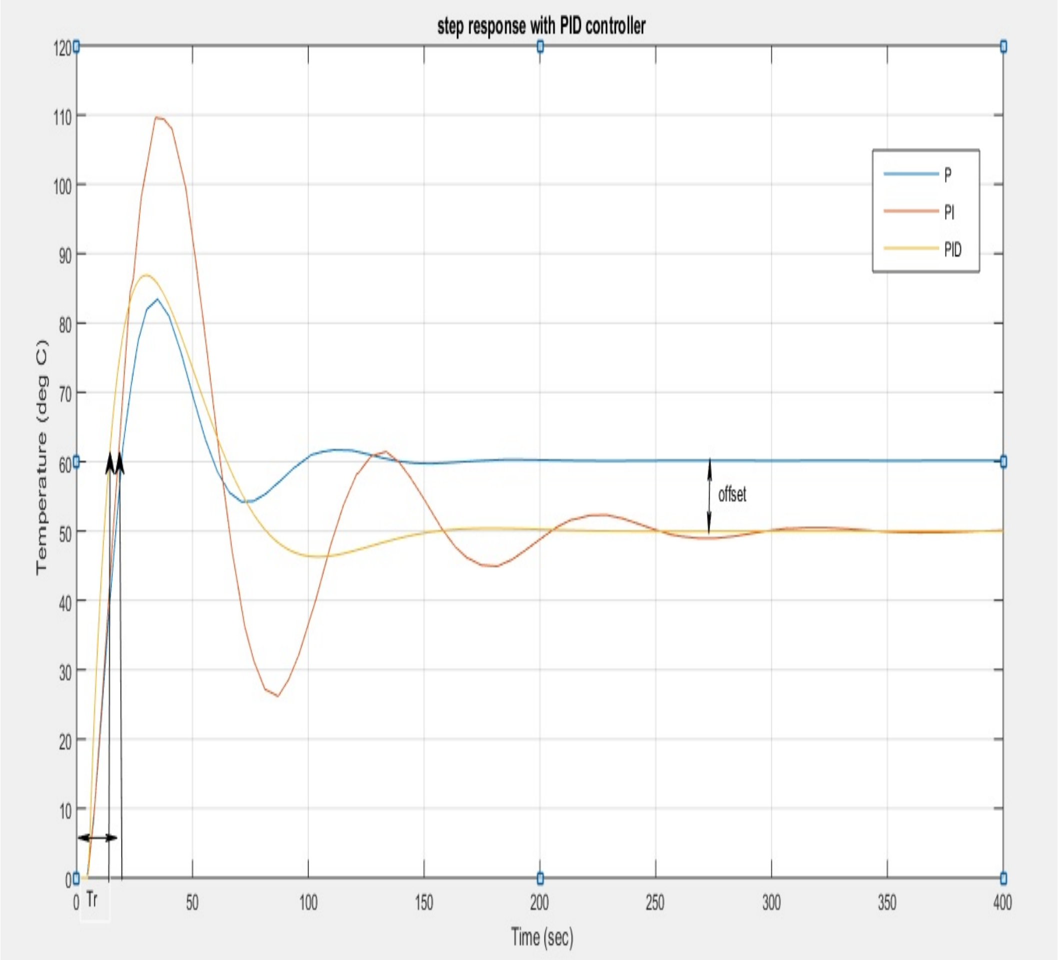

FIGURE 5.2: Simulation results of P,PI,PID

TABLE 5.1: Comparisons between P, PI and PID controller

P control	**PI control**	**PID control**
Fast closed-loop response	Most common controller form	Derivative action reduces oscillation
Non zero steady state error(offset)	Zero steady state error(offset)	Zero offset
	Integral action may induce close-loop instability	Measurement noise amplify

5.2 Feedback plus Feedforward controller

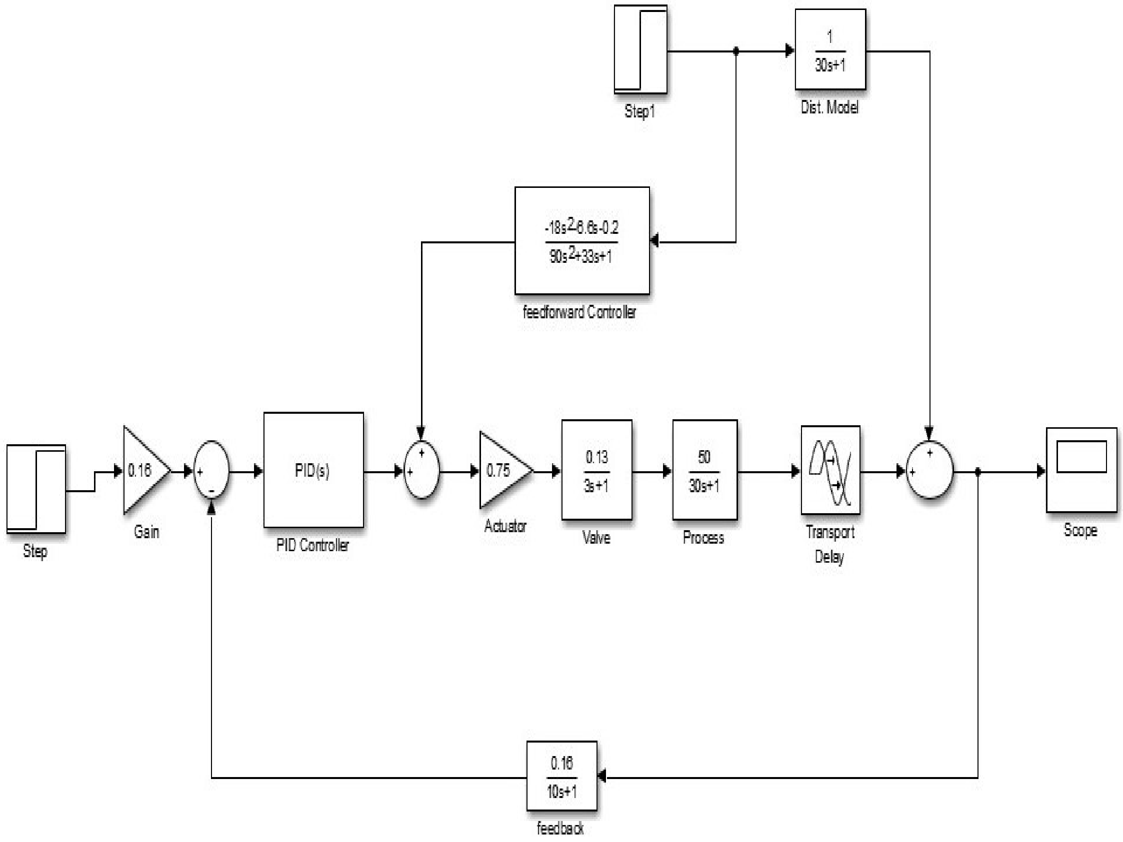

FIGURE 5.3: Simuink model of Feedback plus Feedforward controller

$$G_{ff}(s) = \frac{-18s^2 - 6.6s - 0.2}{(30s + 1)(\lambda s + 1)} \tag{5.3}$$

λ is filter tuning parameter.

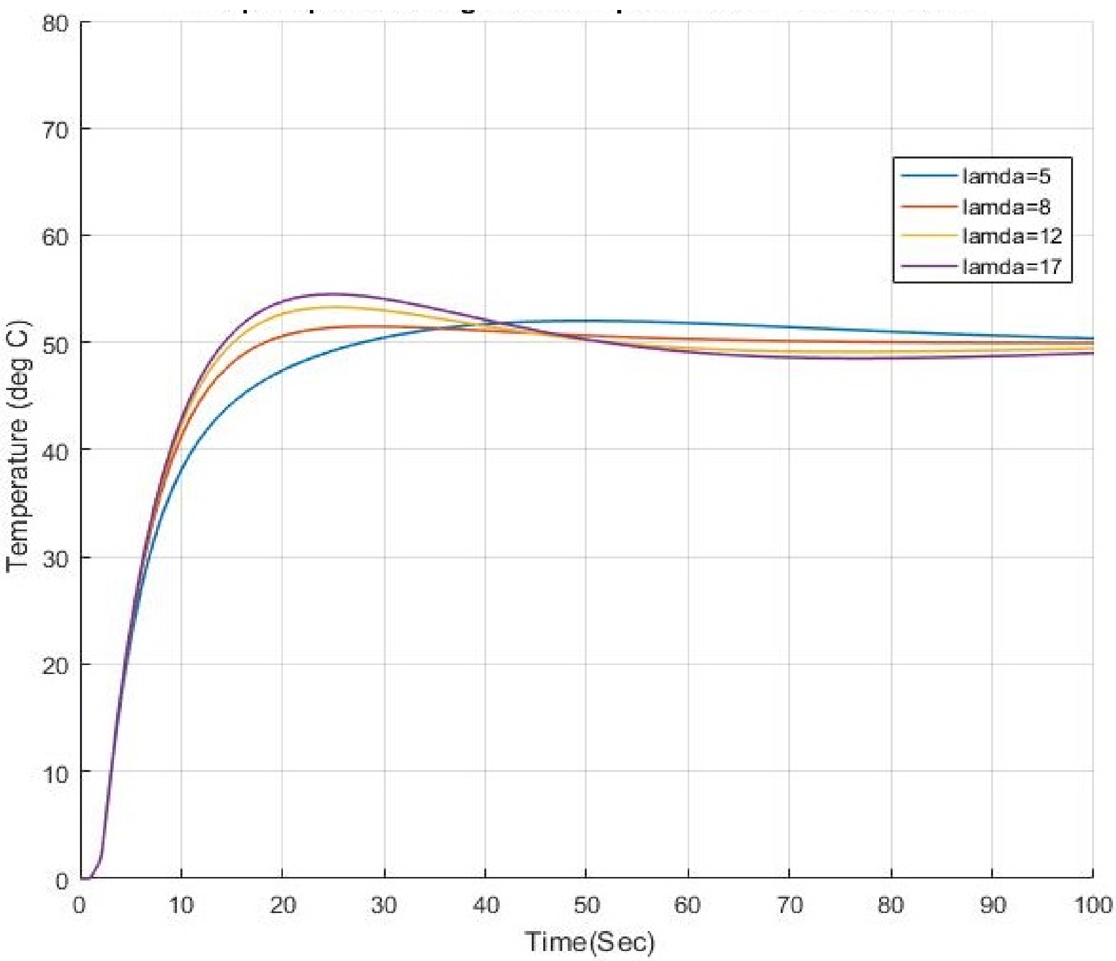

Figure 5.4: Simulation results of Feedback plus Feedforward controller

Taking different vaue s of λ i.e 5, 8, 12, 15 we check the result and we find that for λ value 8 there is less overshoot and less settling time as compared to λ is 12 and 15 .As we see on increasing λ values there is more overshoot and more settling time.

5.3 Internal Model controller

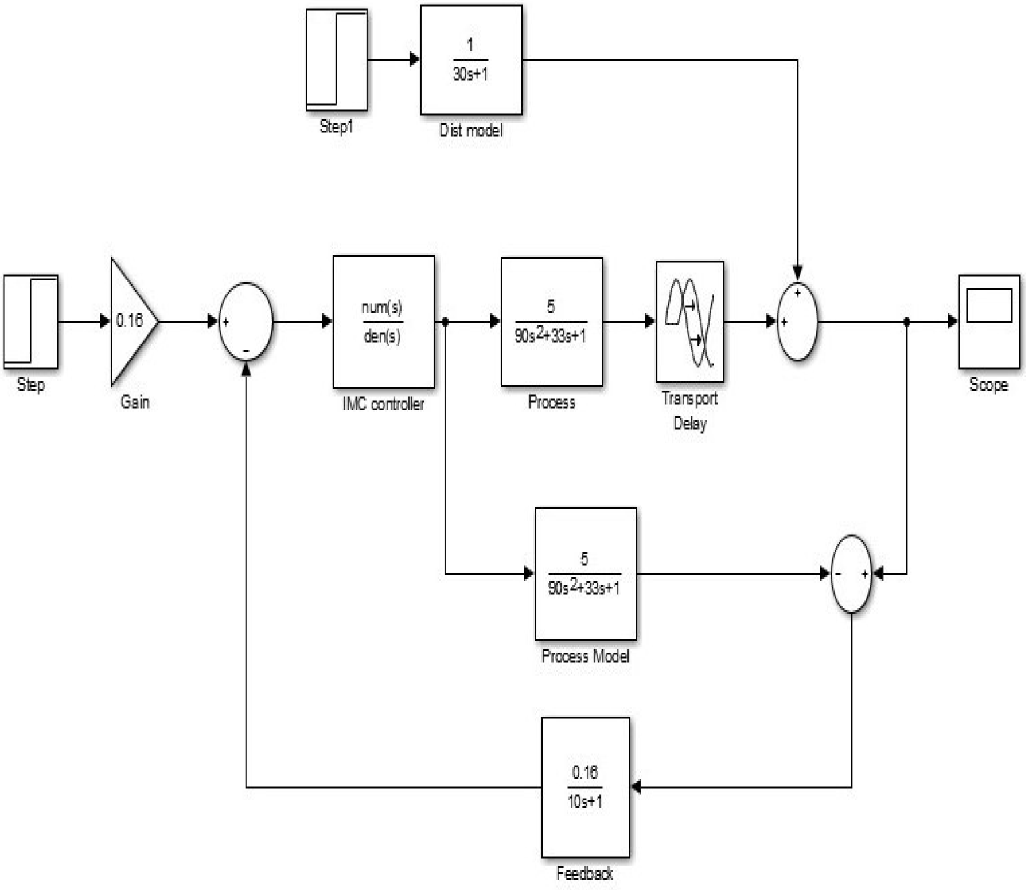

Figure 5.5: Simulink model of IMC

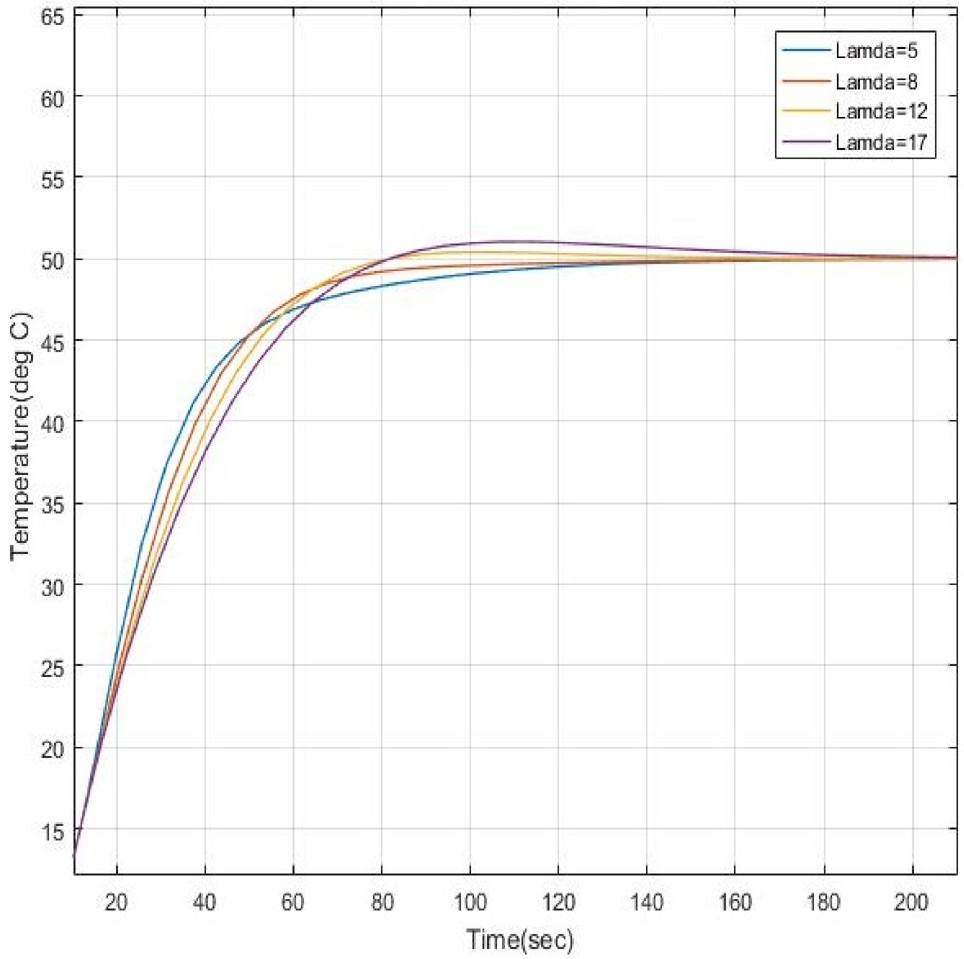

FIGURE 5.6: Simulation results of Internal Model Controller

Figure shows the step response of the shell and tube heat exchanger system when an internal model controller is implemented in the series of the real process and an approximate model of the process is placed in parallel of the real process.

λ is filter tuning parameter.

Taking different vaue s of λ i.e 5, 8, 12, 17 we check the result and we find that for λ value 12 there is less overshoot and less settling time .As we see on increasing λ values there is more overshoot and more settling time.

Comparision of all controllers Response

After applying all the controllers on the heat exchanger system we got the different response on the following aspects such as peak over shoot, settling time, offset error etc.

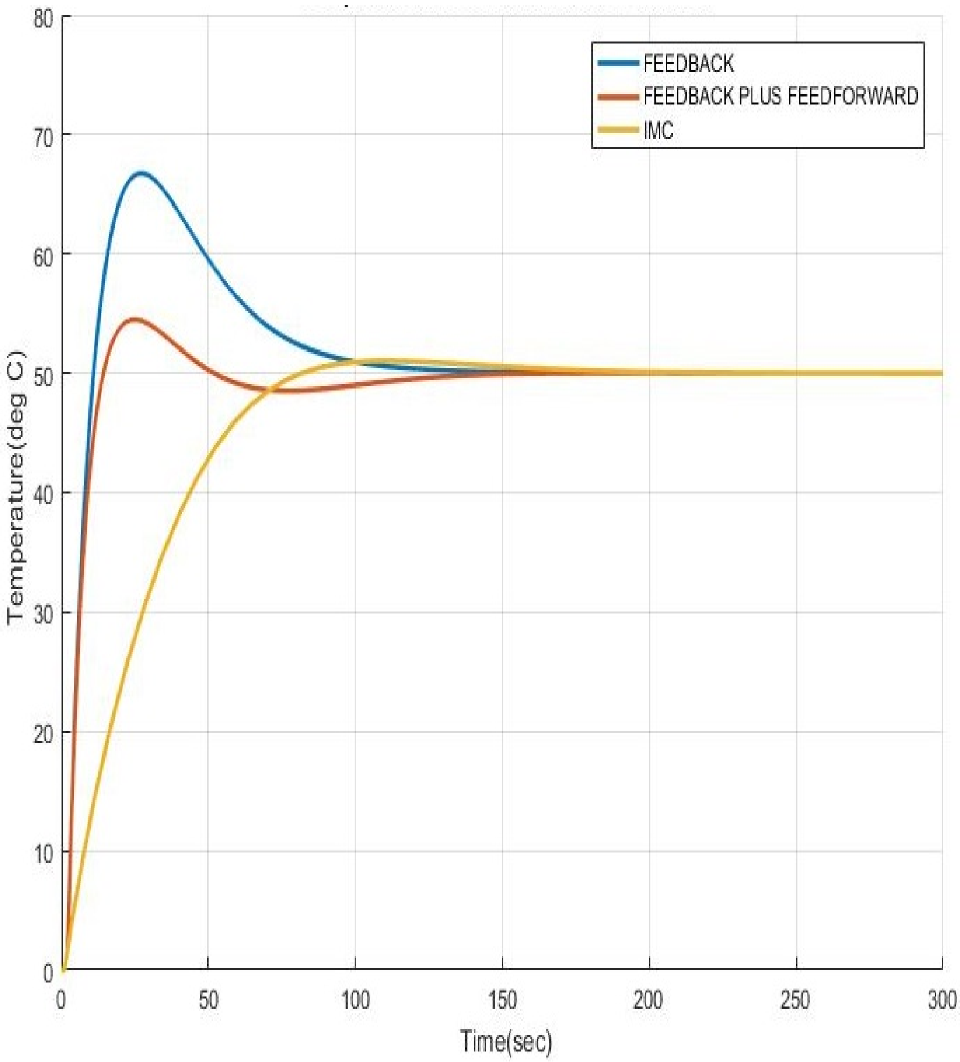

FIGURE 5.7: Simulation results Different Controller

Table 5.2: Performance of controllers

S. No.	Controller	(%) Overshoot	Settling Time (sec)	IAE	ISE
1	Feedback PID	38%	163	189.2	685.7
2	Feedback Plus Feedforward Controller	13%	152	124.4	597.6
3	Internal Model Controller	3%	148	220	789.5

The results shows that feedback PID controller gives very high overshoot of 38%. To compensate this kind of high overshoot a feed forward controller in conjunction with the conventional PID in feedback loop is implemented. By implementing this method the system overshoot was reduced to 13%,. Though the overshoot has some what decreased, it can be further decreased by implementing IMC controller to almost zero.

Chapter 6

Conclusion and Future Scope

6.1 Conclusion

In Simulink model of heat exchanger system I have used the Feedback, , Feedback and Feed forward, and Internal Model Controllers to see the responses of the controllers.I observed that among all the controllers response of the IMC controller is best on the basis of the performance like transient characteristics and error indices.

6.2 Future Scope

Further for real-time measurement we use IMC based PID Controller ,intelligent fuzzy [7], neuro controllers are developed for a shell and tube heat exchanger system.

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