DESIGN AND DEVELOPMENT OF ENHANCED ANTI SURGE CONTROL BY USING SMITH PREDICTOR METHOD

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Field of Study: **INDUSTRIAL CONTROL TECHNOLOGY**

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ABSTRACT

The importance of the anti surge control has became highly concern with the rapid increment of using compressors in industrial technology now a days. The applications of the compressors is varying depends on the process and the product ,this research has designed and developed anti surge controller for pneumatic compressors which are widely used in most of the industrial technologies to supply the plants with required compressed air for continues process and most of the process needs a compressed air with pressure of P = 7 bar, the flow is vary from compressor to others and from process to process this research has been concerned on the most used flow which is Q = 15.66 m^3/min ,according to the process operation surge will occur when sudden blockage happened or during low demand so the process pressure will increase from 7 bar up to 9 bar before the compressor shutdown because of high vibration that yields from the high pressure most of the anti surge control are either PI or PID control and even that these controllers cannot predict the surge phenomena and the worst is the control valve is opened by 10% to 25% so these controllers has been designed and developed by using Smith predictor method and this enhanced Anti Surge controller has been demonstrated by using MATLAB/Simulink the enhanced Anti surge controller prove of an enhancement faster than normal PI or PID controller the result of the enhanced Anti surge controller reach up to 50% of time needed by the normal PI or PID controller

Keywords: anti surge control, smith predictor method

REKA BENTUK DAN PEMBANGUNAN KAWALAN TERCEKIK DENGAN MENGGUNAKAN KAEDAH SMITH PREDICTOR

ABSTRAK

Kepentingan kawalan anti lonjakan telah menjadi perhatian utama dengan peningkatan kepesatan menggunakan pemampat dalam teknologi perindustrian sekarang ini. Aplikasi kompresor berbeza-beza bergantung kepada proses dan produk, penyelidikan ini telah direka dan dibangunkan pengawal anti lonjakan untuk pemampat pneumatik yang digunakan secara meluas dalam kebanyakan teknologi perindustrian untuk membekalkan tumbuhan dengan udara termampat yang diperlukan untuk proses yang berterusan dan paling banyak proses ini memerlukan udara termampat dengan tekanan P = 7 bar, alirannya berbeza dari pemampat kepada yang lain dan dari proses untuk memproses kajian ini telah menjadi perhatian pada aliran yang paling banyak digunakan iaitu Q = 15.66 m3 / min, menurut lonjakan operasi proses akan terjadi apabila penyumbatan secara tiba-tiba berlaku atau semasa permintaan rendah supaya tekanan proses akan meningkat dari 7 bar sehingga 9 bar sebelum pemampat kerana getaran tinggi yang menghasilkan tekanan tinggi kebanyakan kawalan lonjakan sama ada PI atau Kawalan PID dan walaupun pengawal ini tidak dapat meramal fenomena lonjakan dan yang terburuk adalah injap kawalan dibuka sebanyak 10% hingga 25% jadi kawalan ini telah direka bentuk dan dibangunkan dengan menggunakan kaedah peramal Smith dan pengawal Surge yang telah dipertingkatkan telah ditunjukkan dengan menggunakan MATLAB / Simulink pengawas Anti Peningkatan yang membuktikan penambahbaikan lebih cepat daripada normal PI atau pengawal PID hasil pencapaian pengawal Anti surge ditingkatkan sehingga 50% masa diperlukan pengawal PI atau PID biasa

Kata kunci: kawalan lonjakan anti, kaedah peramal smith

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Q	:	Volume flow
ΔQ	:	Change in Volume flow
R_C	:	Compression Ratio
V	:	Volume
ΔV	:	Change in volume
C	:	Capacitance Pressure Vessel /Chamber
R	:	Gas flow resistance
r	:	Radius of the pipe
L	:	Length of the pipe
E	:	Total energy
ΔE	:	Change in the total energy
W	:	Total work
Q_h	:	Total heat
ΔQ_h	:	Change in total heat
KE	:	Total in kinetic energy
ΔKE	:	Change in total kinetic energy
PE	:	Total potential energy
ΔPE	:	Change in total potential energy
FE	:	Total flow energy
ΔFE	:	Change in total flow energy
R_{gas}	:	Perfect gas constant
T	:	Temperature
m	:	Mass
Z	:	Compressibility factor

ρ : Density

V_s : Specific volume

U : Internal heat energy

ΔU : Change in internal heat energy

SFEE : Steady Flow Energy Equation

PI : Proportional Integral

PID : Proportional Integral derivative

h : Height

v : Velocity

CHAPTER 1: INTRODUCTION

1.1 Introduction

Anti-Surge Control System works based on the detection the of the process compression when it is operating under low flow and forthcoming to the surge line and consequently take action to reverse the flow of the compressed gas .This recycling process will keep the flow through the compressor steady, resulting in stable working conditions. It is e achieved normally by opening a control valve in a recycle line which called Anti-Surge Control Valve, returning the discharge gas to the inlet of the compressor.(Ali Ghanbariannaeeni & Ghazalehsadat Ghazanfarihashemi,2012)

Surge is an unstable mode of operation for the compression system which occurs during low mass flows. Surge not limits the performance and efficiency of the compressor only but it can also damage the components of the compressor and its auxiliaries due to the high mechanical and thermal loads involved. moreover, the surge associated with vibrations can result in high level of noise (van Helvoirt, 2007).

In general, companies are protecting their technologies and specifications and that limits the possibility to obtain direct information from the developers. Conversely, the same behavior of protection results in open patents to the general public. Most of the reviewed literature articles on general dynamic compressors and control are conferred with the aim of augmented insight and considerate (Kvangardsnes, 2009).

In the industrial practice two separate PID controllers are usually employed: the pressure controller and the anti surge controller. The pressure controller has a cascade control arrangement. The slave loop is a velocity controller. Its set point is the output of the master loop where the torque is the manipulated variable is for the driver. The pressure controller is the master loop. The outlet Pressure of the compressor is the controlled variable, while the output of the slave loop is the remote set point. There are tow stages to tune pressure controller first stage by lambda tuning technique and then second stage testing by trial and error (2nd IFAC Workshop on Automatic Control in Offshore Oil and Gas Production, May 27-29, 2015, Florianópolis, Brazil)

This research project is based on fixed speed compressor so only one PI/PID have been designed ,developed and enhanced by Smith predictor

1.2 Problem Statements

Generally the compressor is surrounded by many critical issues that limit its performance figure 1.1 show the limitation boundaries and

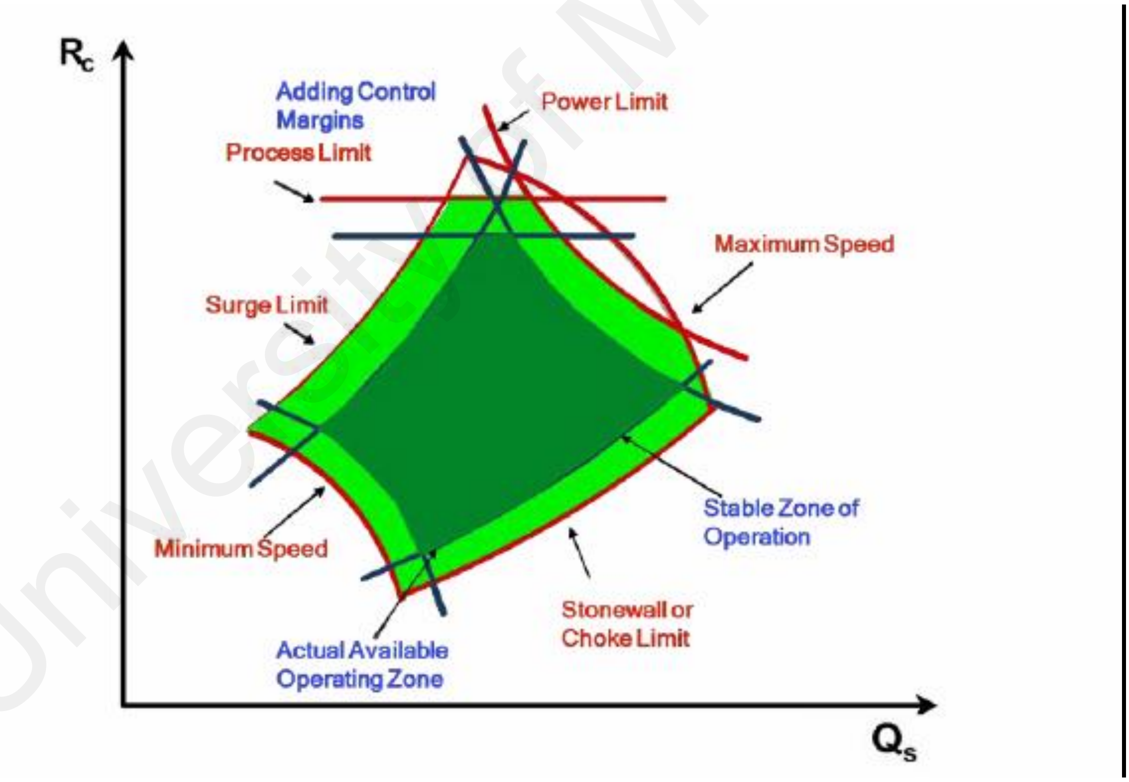

Figure 1.1: Rc Compression Ratio to Qs Volumetric Flow Compressor Map with Boundaries (Turbomachinery Laboratory, Texas A&M Engineering Experiment Station 2012)

It is clear that all boundaries are linked together for example the speed is implemented under power, volumetric flow is implemented under pressure and both of choke and surge are implemented under process, because of that mostly we need to control all boundaries (Saul Mirsky, PE et al ,2012)

This project has discussed the surge limit boundary which is under process condition that means most important parameters for this study are the pressure and the volumetric flow, the surge phenomena is mitigated by designing special controller called anti surge controller where its final control element called Anti Surge Control valve, most of the anti surge controller are either PI or PID controller and most of the designers are focusing on the final control element by increasing the speed of the Anti Surge Control Valve to protect the compressor from surge phenomena in additional to that they keep the anti surge control valve opened by 10% to 25% for more precaution could happened due time delay and bring the compressor to the Steady Flow Energy Equation SFEE state

This project has paid more attention to the controller In this study the PI and PID controller will be improved by developing predictor to be suitable with the controller to achieve steady state, as we mentioned above that this project under process condition and usually the regulatory control of any process activities are ranged from seconds up to several minutes as shown in figure 1.2

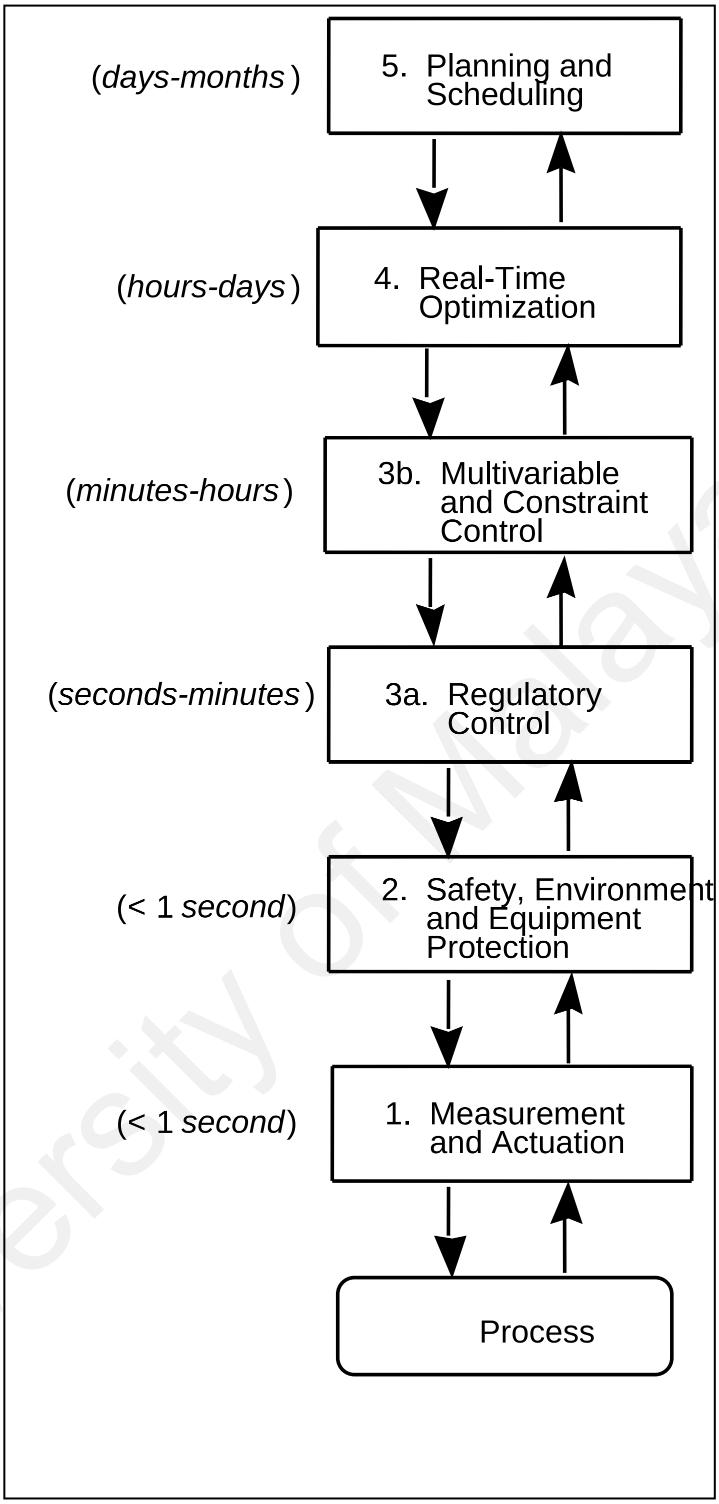

Figure 1.2: (Hierarchy of Process Control Activities) (Seborg, Mellichamp, Edgar, & Doyle III, 2010).

1.3 Objectives

Main objectives of this project are:

1) To design and development of enhanced PI/PID Controller by using Smith predictor method to reach up to 50 % time response faster than normal PI/PID controller.

2) To obtain optimal time response of the controller by using MATLAB /Simulink simulation.

1.4 Scope of Projects

Scope of this project will include the development and design of enhanced Anti surge Controller by using Smith predictor until specifications mentioned in section 1.3(1) is achieved.

All The structure of the PI / PID controllers is design and tuned based on internal model control tuning or tested by try and error. Then the values of the proportional, integral and derivative are set as mentioned in table 1.1 then the smith predictor is developed to mitigate the time delay of the system the stability of the system has been studied by using MATLAB/Simulink

Table 1.1: PI/PID Controller enhanced by Smith Predictor specifications

Items	Specifications	
	PI controller	PID controller
Kp	6.3	6.2
Ki	0.35	0.8
Kd	0	0.18

This project will be carried out using MATLAB/Simulinlk software to design PI/PID controllers enhanced by using Smith predictor. The time response and stability of the system will be analyzed when pressure is disturbed. Disturbance pressure will be in the range of 7-9 bar since the normal instrument air pressure is just7 bar.

1.5 Thesis Organization

This report consists of 5 chapters and begins with chapter 1 with the introduction to this project and problem statement that concerns. While chapter 2 focuses more on the literature review related to the compression process, pressure and flow theories. Chapter 3 will have the projects flow chart, mathematical modeling of the projects it, PI / PID controller and smith predictor. Meanwhile chapter 4 will discuss the result obtain from simulation using MATLAB/Simulink . Finally, chapter 5 contains discussion on overall chapters, conclusions and recommendation for future work.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter consists of literature review based on thermodynamic principles, compression process concepts that are related to the implementation of universal gas low. Other than that, explanation the compressor map, surge phenomena, surge control with recycle valve and implement the block diagram of the compressing system and its disturbance .

2.2 Compression Process

Compressors play vital role in most of industries specially in oil and gas plant while some gases are compressed according to the needs of operations where as the compressed air is the heart for all of these industries usually air is compressed and processed to be sent for deferent usage inside the plant actually the air enters to the compressor with atmospheric pressure of 1 bar and compressed to reach up to 7 bar which is the standard pressure for many equipment and facilities inside the plant as known the ideal gas low states

$$\frac{PV}{T} = mR_{gas}T \qquad (2.1)$$

(Tarik AL- Shemmeri,2010)

Where mRT are constants so

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \qquad (2.2)$$

and this low depends on the nature of the thermodynamic process but mostly the comparison process is isothermal process so no change in the temperature and this happened by subjecting this compression process to cooling medium like cooling oil to maintain the temperature fixed so

$$T_1 = T_2 \quad (2.3)$$

As mentioned before the suction pressure is 1 bar and the discharge pressure is 7 bar so

$$P_1V_1 = P_2V_2 \quad (2.4)$$

$$\text{where } P_1 = 1 \text{ bar and } P_2 = 7 \text{ bar so } V_1 = 7V_2 \quad (2.5)$$

and this volume depends on the compressor specifications

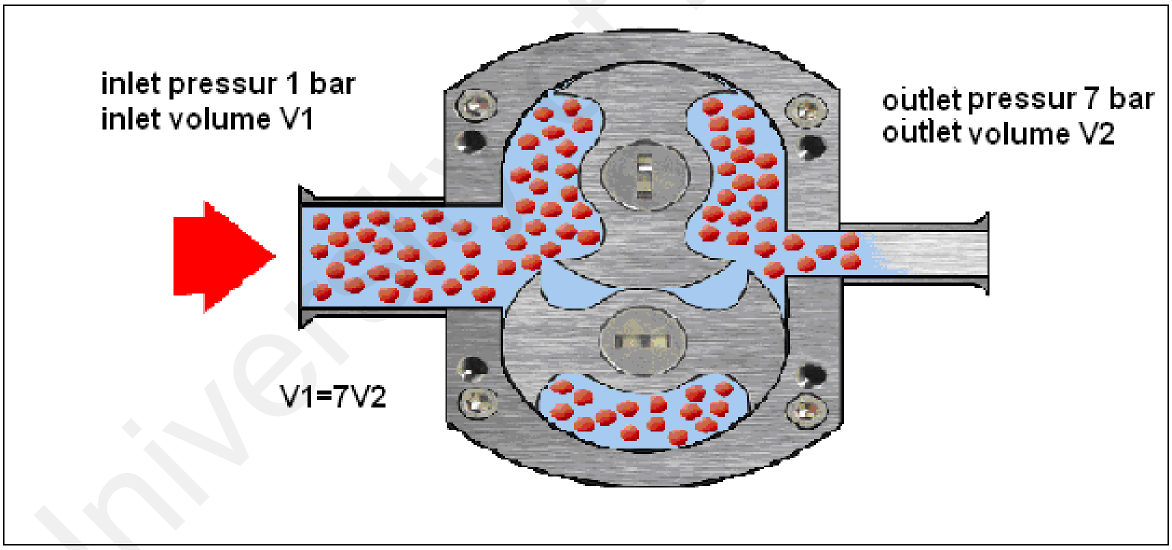

Figure 2.1: Compression Process.

Modified picture explain the compression process (Continuum SDN BHD,2013)

2.2.1 Compressibility of Air

The Compressibility factor Z is the factor which measure the deviation of any compressed gas from the behavior of the perfect gas during compression process so when Z approach to 1 for a given gas that means this gas's behavior approach to the behavior of the perfect gas to calculate the factor Z

$$Z = \frac{Pv_s}{R_{gas}T} \quad * \tag{2.6}$$

(Tarik AL- Shemmeri,2010)

So our process conditions are at $P = 10^5$ Pa , Vs=0.75 m^3/kg , T=300k and $R_{air} = 287.58$ j/kg.k so Z=0.9950 and by this obtained value we can assume that the behavior of the compressed air is same f the perfect gas behavior (Tarik AL-Shemmeri,2010)

* note here v_s is the specific volume $v_s = \frac{1}{\rho}$ and ρ of air =1.225 kg/m^3

2.2.2 Compression Mathematic Modeling

This compression mathematical modeling based on the compressor which has the following specification as shown in table 2.1

Air Compressor Power requirements Calculator

Pumping rate	15660.00	L/min		
Inlet Pressure	1.00	bar		
Final fill pressure	7.00	bar		
Inlet Temperature	20.00	Outlet Adiabatic temp		237.89
Compressor Entropy Efficiency	71.00	%		
Drive Motor Power	69608.86	Watt		
	93.35	horsepower		

Single Phase Electrical Requirements

Motor Efficiency	75.00	%
Voltage	220.00	Volts
Current	421.87	Amps

3-phase electrical Motor Requirements

Motor Efficiency	75.00	%
Inter-phase voltage	380.00	Volts
phase current	141.01	Amps

THERMODYNAMIC CONSTANTS

Gamma=	1.4	fgas Constant compression adiabatic temperature rise
Entropy Change =	796.00	J/K/m^3

Table 2.1 Compressor Specification source www.scubaengineer.com by Author:-

Steve Burton C.Eng

The specifications mentioned in table 2.1 has been proved by applying the first thermo dynamic low on figure 2.2 total energy can be calculated as below

$$\Delta E = Q_h - W \quad (2.7)$$

(Tarik AL- Shemmeri,2010)

Where ΔE is the total change in energy and Q_h is the amount of heat (+ given to the system – taken from the system) and W is the work (+ done by the system – done on the system) and the first low of thermodynamic can be written as

$$\Delta E = Q_h - W = \Delta KE + \Delta PE + \Delta FE + \Delta U \quad (2.8)$$

Where

$$\Delta KE = \frac{1}{2} m(v_2^2 - v_1^2) \quad (2.9)$$

It's the kinetic energy which equal to zero because no change in the velocity of the gas

$$\Delta PE = mg(h_2 - h_1) \quad (2.10)$$

It's the position energy which is equal to zero because no change in height

$$\Delta FE = m(P_2V_2 - P_1V_1) \quad (2.11)$$

It's the flow energy which is not zero because pressure and volume are changed due to compression process

$$\Delta FE = m(U_2 - U_1) \quad (2.12)$$

is the internal energy which can be ignored due to cooling process which maintain the temperature of gas is same in the suction and in the discharge beside what we have mentioned the total energy depends on thermodynamic process features and most of the air compressor has cooling medium so its process is isothermal process so to calculate the energy of this compression process and according to the specification in table 2.1 as explain in figure 2.2

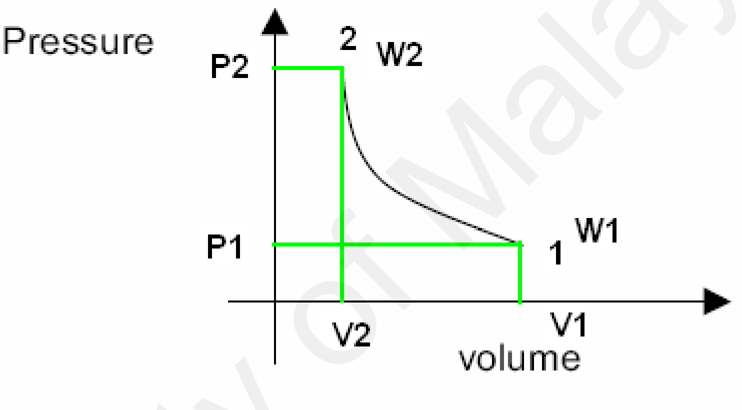

Figure 2.2: total energy in the compression process

$$\Delta E = W_{12} = \int_{v1}^{v2} P\, dv \quad (2.13)$$

but as known $\frac{P_1 V_1}{T_1} = mRT$ where mRT is constant so $\frac{P_2 V_2}{T_2} = mRT$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \text{ where } T_1 = T_2$$

$$\text{so } P_2 = \frac{P_1 V_1}{V_2} \tag{2.14}$$

But $P_1 = \dfrac{mRT_1}{V_1}$

$$\text{so } P_2 = \frac{mRT_1}{V_1} \times \frac{V_1}{V_2} \tag{2.15}$$

$$\Delta E = W_{12} = \int_{v1}^{v2} \frac{mRT_1}{V_2}\, dv \text{ then} \tag{2.16}$$

$$W_{12} = mRT_1 \times \text{lin}\, \frac{V_2}{V_1} \tag{2.17}$$

So from $W_{12} = mRT_1 \times \text{lin}\, \dfrac{V_2}{V_1}$ where V is equal to 8.7 liter and

$\rho = \dfrac{m}{V}$ m so $m = \rho V$ where $V = 8.7 \times 10^{-3}\, m^3$ and

$\rho = 1.225 \text{kg/m}^3$ so $m = 8.7 \times 10^{-3} \times 1.223$ so $m = 10.6575 \times 10^{-3}$ kg

R_{air} is specific gas constant of air and $R_{air} = 287.058$ J/kg.K

T is ambient temperature and T =300 k so the amount of work done is given

$$W_{12} = mRT_1 \times \text{lin}\, \frac{V_2}{V_1} = 10.6575 \times 10^{-3} \times 287.058 \times 300 \times \text{lin}\, \frac{V_2}{7V_2} = 1784.943 \text{ j}$$

So this is the amount of energy to compress around of 8.7 L of air with in 0.033333 s which is almost the same power in the table given above in table 2.1.

To find out the mathematic model for the compressor process with the specifications mentioned above in table 2.1 two parameters have to be defined

Gas flow Resistance

Gas flow resistance is the deferential pressure over the change in flow rate of the gas

$$R = \frac{\Delta P}{\Delta Q} = \frac{P_2 - P_1}{Q} \text{ where } Q = 15.66\, m^3 / m \Rightarrow Q = \frac{15.66}{60} = 0.261 m^3 / s$$

$$R = \frac{\Delta P}{\Delta Q} = \frac{P_2 - P_1}{Q} = \frac{7 - 1}{0.261} = 22.988\, \text{bar/m}^3/\text{s} \tag{2.18}$$

(Katsuhiko Ogata- Shemmeri,2010)

Capacitance Pressure Chamber

Capacitance pressure system can be defined as change in the amount of the compressed gas to the change in gas pressure

$$C = \frac{dm}{dP} \tag{2.19}$$

but $m = \rho V$ so

$$C = \frac{d(\rho V)}{dP} = \frac{V d\rho}{dP} \tag{2.20}$$

Where the compressor chamber is fixed and the density of compressed air is changing due to the pressure change

(Katsuhiko Ogata,2010)

Density of air at ambient pressure can be calculated according to following formula

$$\rho_{1bar} = \frac{P_{1bar}}{R_{air} \times T} = \frac{10^5}{287.058 \times 298.15} \text{so} = 1.168 \ \text{Pa/J/kg.} \qquad (2.21)$$

in other hands it can be expressed $\rho = 1.168 \ \text{kg/m}^3$ and the density of the air at 7 bar can be calculated as follow

$$\rho_{7bar} = \frac{P_{7bar}}{R_{air} \times T} = \frac{7 \times 10^5}{287.058 \times 511.04} \text{so} = 4.771 \, \text{Pa/J/kg.} \qquad (2.22)$$

and also can be expressed $\rho = 4.77 \ \text{kg/m}^3$ note here the value of temperature is the outlet temperature according to the table 2.1

So to calculate the capacitance of the pressure chamber $C = \frac{Vd\rho}{dp}$ and to calculate V according to the table 2.1 the pumping rate is $Q = 15.66\text{m}^3 / \text{min}$ so if the motor driver is four poles and 60 Hz frequency

$$\text{RPM} = 120 \frac{f}{\text{number of poles P}} = 120 \frac{60}{4} = 1800 \, \text{RPM}$$ so if RPM converted into RPS will get 30 RPS so the pumping rate will be $0.261\,\text{m}^3/\text{s}$ and this is the amount of pumping rate in 1 second giving by 30 rotation so at 1 rotation the pumping ratio will be $8.7 \times 10^{-3}\,\text{m}^3$ which is $8.7\,\text{liter}$ and that is the volume of the compression chamber so to calculate capacitance of the pressure chamber

$$C = \frac{Vd\rho}{dP} = \frac{8.7 \times 10^{-3}(4.77 - 1.168)}{(7 - 1)} = 5.2229 \times 10^{-3} \ \text{kg/bar} \qquad (2.23)$$

Compression Process Transfer Function

Looking to the following figure 2.3 its clear that $C = \frac{Qdt}{dP_o}$ and $R = \frac{\Delta P}{\Delta Q}$ where intitialy $Q = 0$ so $R = \frac{dP}{Q}$ then $Q = \frac{dP}{R}$ by compensate the value of C in equation we can get $CdP_o = \frac{dP}{R} \Rightarrow CdP_o = \frac{P_i - P_o}{R}$ by taking the laplace transform to the equation $CdP_o = \frac{P_i - P_o}{R}$ so

$$\ell(CdP_o) = \ell(\frac{P_i - P_o}{R})C \text{ then } RCSP_o(S) = P_i(S) - P_o(S) \quad (2.24)$$

$P_o(S)(RCS + 1) = P_i(S)$ by taking the value of R from equation (2.18) and the value of C from equation (2.23)

$$\frac{P_o(S)}{P_i(S)} = \frac{1}{RCS + 1} = \frac{1}{0.12006S + 1} = \frac{8.33}{S + 8.33} \quad (2.25)$$

(Katsuhiko Ogata, 2010)

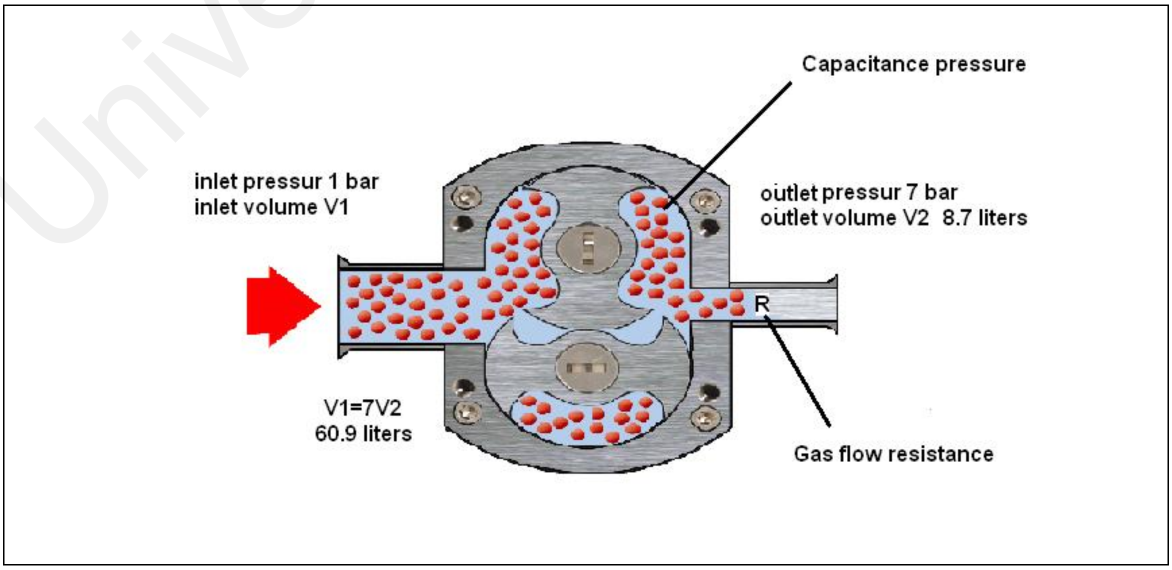

Figure 2.3: transfer function explanation

Modified picture explain the compression process (Continuum SDN BHD,2013)

Process transport line and its lag time

The flow rate of this compressor is $Q = 15.66\, m^3 / min$ as mentioned in table (2.1) and the transportation time of the gas from the outlet of the compressor to the pressure transmitter as shown in figure 2.4

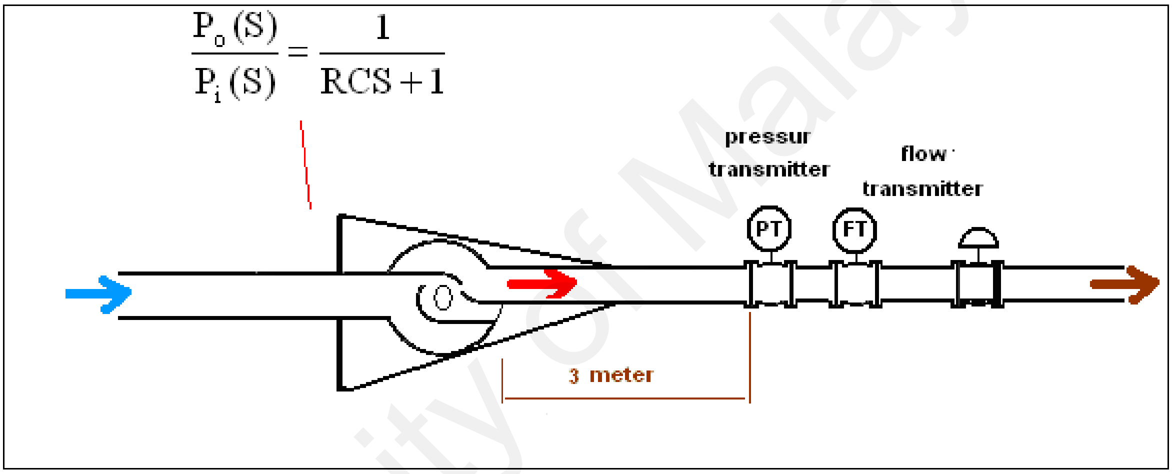

Figure 2.4: transfer transport line distance explanation

is usually around 3 m then the traveling time of the compressor product can be found according to the formula

$$t = \frac{V}{Q} = \frac{\pi r^2 L}{Q} = \frac{\pi \times (12'' \times 0.254)^2 \times 3}{15.66} = 0.05591\, min = 3.3547\, s \quad (2.26)$$

Where

t is the traveling time

L is pipe length from the outlet of the compressor to the pressure transmitter 3m r is the radius of the pipe 12 inches

Q is the flow rate of the air

So it's clear that the lag time is equal to 3.3547 s and the transfer function of the time delay will be as following

$$T(S) = e^{-3.3575S} \tag{2.27}$$

(BABATUNDE A. OGUNNAIKE &W. HARMON RAY,1994)

Compression Process disturbance Transfer Function

The main disturbance for the any compressor when its consumers don't need demand as shown in figure 2.5 which the storage tank that because the compressed air must be stored in a tank to ensure the availability of compressed air when compressor is down this tank should be big to meet the required demand if the compressor is down for enough time depends on the importance of the, process most of the compressed air consumers are pressurized rooms and equipments, process and control valve lastly is the combustion equipment like boilers and furnaces

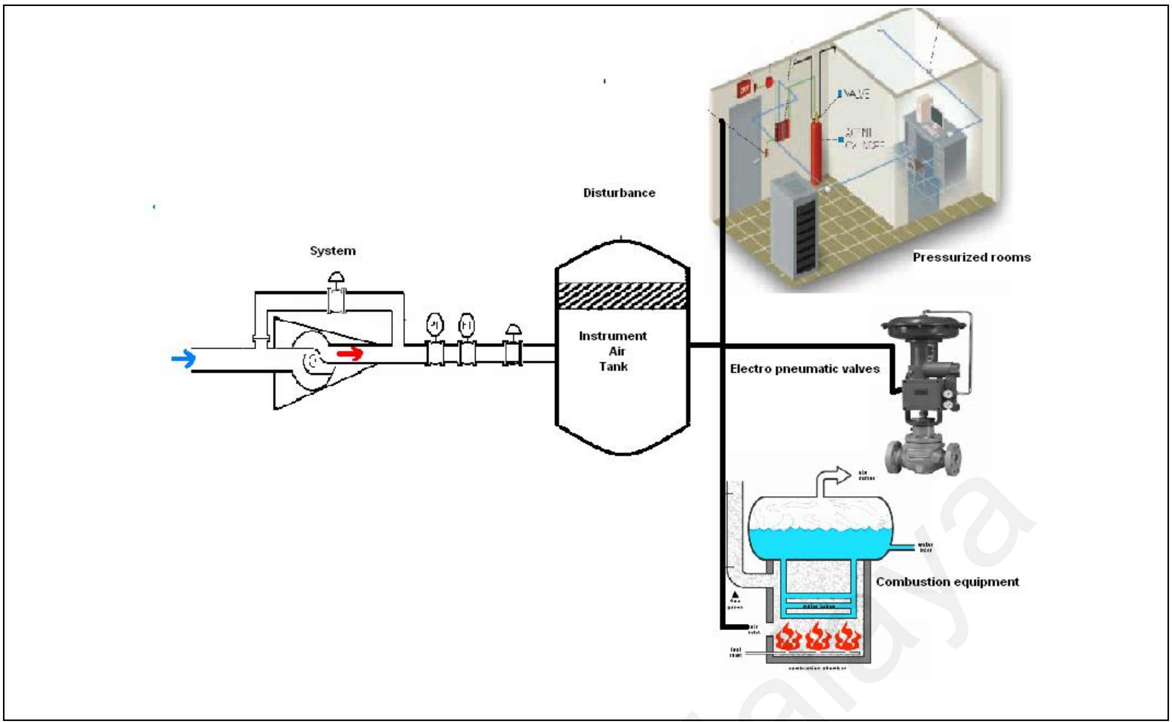

Figure 2.5: shows the vital consumer of compressed air

(modified from Emerson,nova gas dmfiresafety 2005,2017,2012)

Its very clear that the tank system is pressurizing system almost same like the compression system because they are connected together the only different is the capacity chamber C it will be too big in the tank note here there is another way to calculate the capacity chamber

As have been proved before the compression system transfer function is $\frac{P_o(S)}{P_i(S)} = \frac{1}{RCS+1}$ and it's the same for the tank its obverse that the pressure and the is same from the outlet of the compressor to the tank but the capacity of the tank is deferent so to calculate capacity pressure chamber C

$$C = \frac{dm}{dP} \tag{2.28}$$

but $m = \rho V$ so $C = \frac{d(\rho V)}{dP} = \frac{Vd\rho}{dP}$ and

$$PV = mR_{gas}T \text{ but } V = \frac{m}{\rho} \text{ so } P\frac{m}{\rho} = mR_{gas}T$$

$$\text{so } P = R_{air}T\rho \tag{2.29}$$

$$\text{Then } dP = R_{gas}Td\rho \Rightarrow \frac{dP}{d\rho} = R_{gas}T \tag{2.30}$$

$$C = \frac{Vd\rho}{dP} = \frac{V}{dP/d\rho} \tag{2.31}$$

$$C = \frac{V}{R_{air}T} = \frac{4\times 3\times 30}{287.058\times 298.15} = 4.206\times 10^{-3}\,C\,Kg/bar \tag{2.32}$$

So by taking the value of R from equation (2.18) and the value of C from equation (2.32) the disturbance transfer function will be

$$\frac{P_o(S)}{P_i(S)} = \frac{1}{RCS+1} = \frac{1}{0.0967S+1} = \frac{10.342}{S+10.342} \tag{2.33}$$

2.3 Compressor Map

It's a graphical depiction of compressor performance, usually a plot of head as a function of flow so each compressor has its specified map depends on its maximum flow rate and on its output pressure

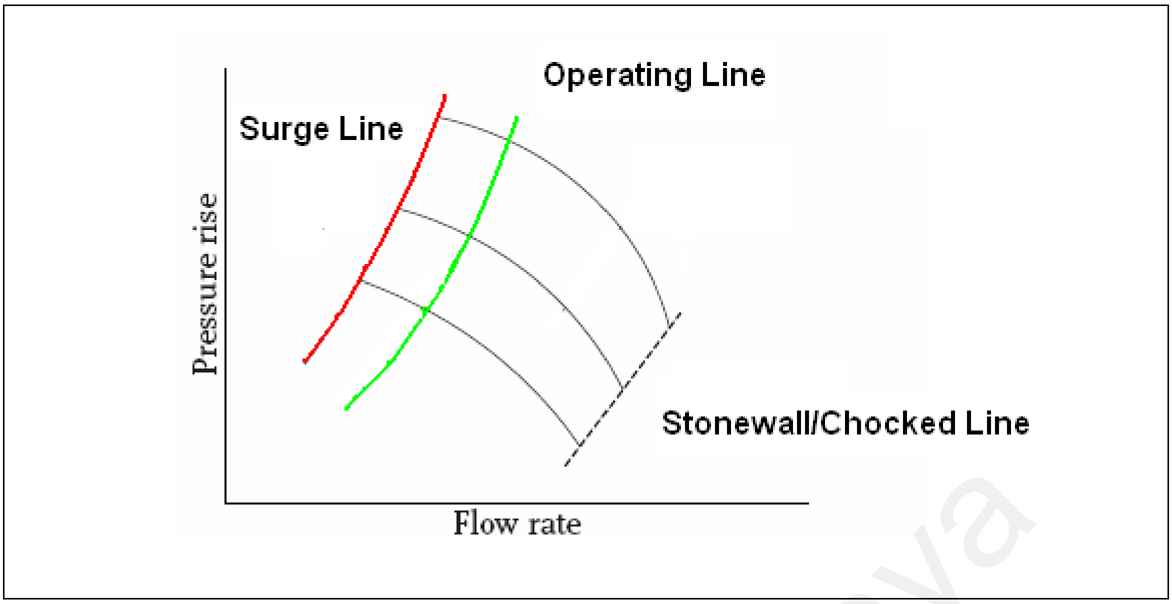

Figure 2.6: Compressor Map

2.3.1 Compressor Surge phenomena

Actually surge occurred when the compressed air flow face a restriction like sudden blockage so its pressure increased more than the outlet compressor pressure so logically the flow of will go from high pressure to the low pressure and then back to the discharge of the compressor which makes the compressor to surge and cause high vibration to the compressor and damage the compressor internal parts as shown if figure 2.7

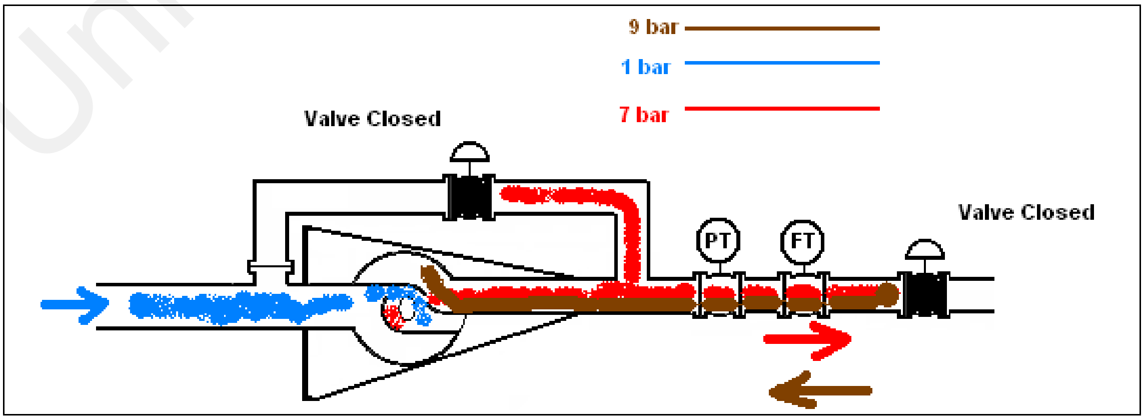

Figure 2.7: Compressor surge Process description

Surge is a dynamic instability of the gas that causes flow reversal inside the machine when the compressor is surging, the oscillatory behavior of the gas flow causes vibrations that can damage blades, casing and bearings (Boyce, 2012)

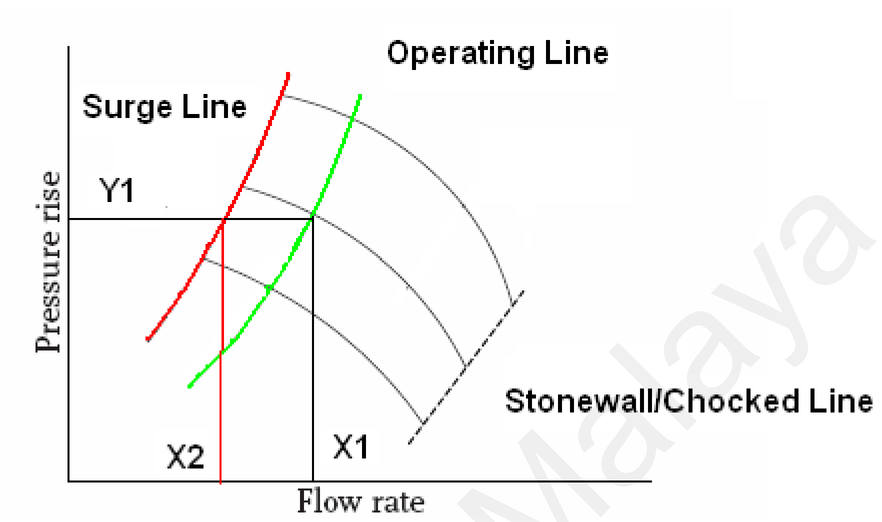

Figure 2.8: Compressor surge explanation where if the compressor is set to work at pressure Y1 and flow rate of X1 no surge occurred but if the flow decreased up to X2 with same pressure surge will occurred

2.3.2 Compressor Surge Line definition

Each compressor has its calculated surge line which is predetermined during the designing and manufacturing steps although before putting any compressor on service surge line must be obtained physically and this step must be done on site in the same location where the compressor will serve for not in the location of the manufacturing the compressors because some compressors will serve in hot conditions like middle east or tropical countries and other compressors will serve in cold weather like in Alaska or Siberia and the changing in the temperature will effect on the flow rate according to $\frac{PV}{T} = mRT \text{ where } mRT \text{ is constant so } \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ where T1 here is the temperature where the compressor will serve all of the time so surge line is identified by start up the compressor unloaded and then load it by 25%,50%75% and 100% then after setting the compressor flow rate the outlet valve is closed slowly until the surge is being detected four points of surge will be detected and counted then physical surge line will be implemented inside the controller where the controller has to run the compressor around 10% away from the physical surge line as shown in figure 2.9 (S. Dominic , U. Maier ,2014)

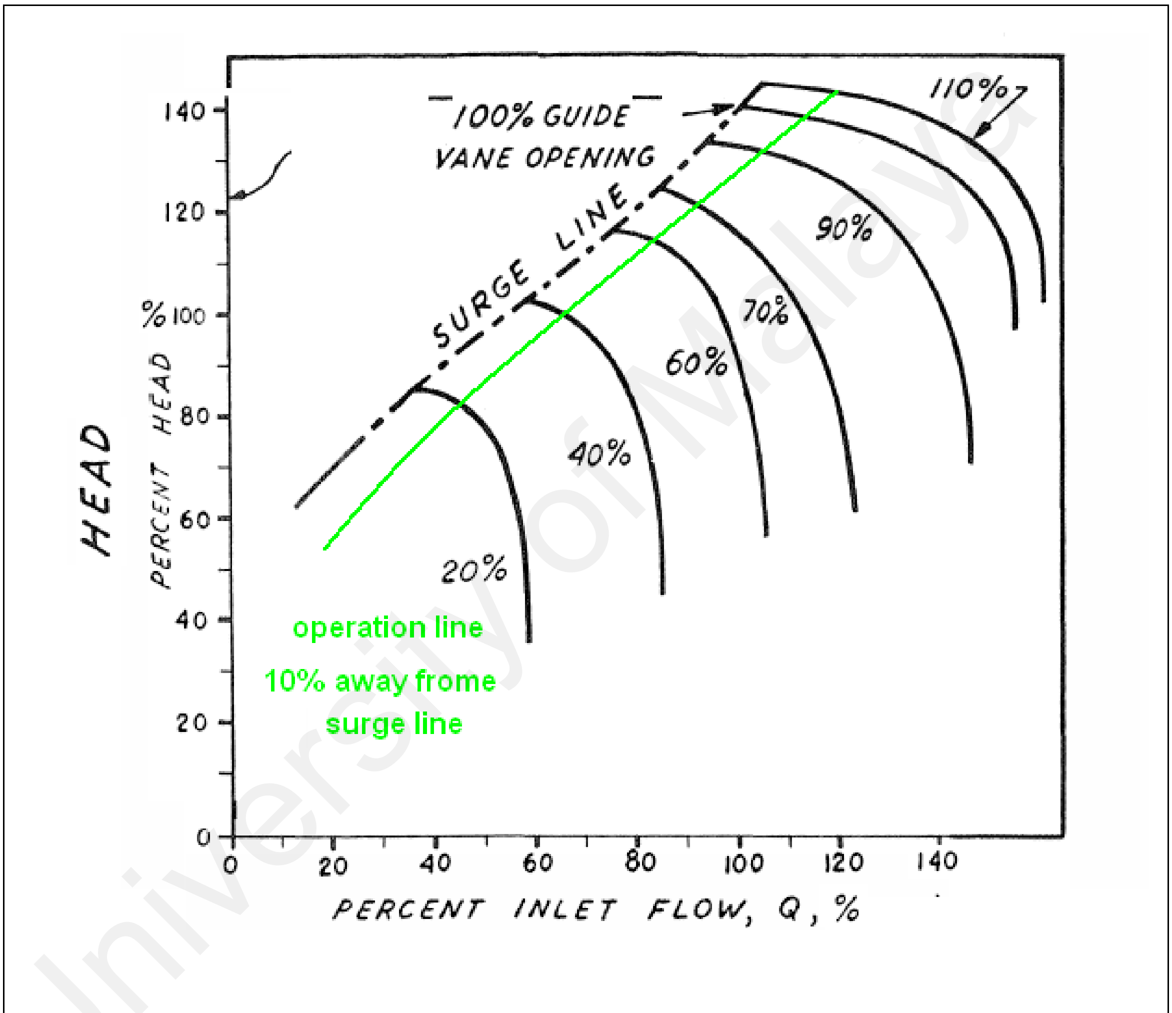

Figure 2.9: Determination the surge line of the compressor "Boyce Engineering International, Incorporated Houston, Texas

2.4 Anti Surge Control Technique

A comprehensive overview and discussion of different surge control strategies from its start to 1990 is presented. Surge avoidance schemes are grouped into four categories.

The categorization is based on how the three variables suitable to describe proximity to surge are combined into a control variable (van Helvoirt, 2007).

1) First category "Control by comparing Pressure ratio to the flow" and encompass strategies where only flow and differential pressure across the compressor are measured. The control line is usually established by a static relationship between the measurements. The author describes some controller structures. A trend is that the inventions have special means for reacting to rapid disturbances. Also, the controller tuning parameters are not static, but depend on the rate of approach or distance to the control line. 2

2) Second category "Control by neglecting the measurements of Pressure ratio", the control is achieved by comparing rotational speed of the compressor and the flow

3) Third category , "PLC Microprocessor Based Controller", is characterized by counting extra measurements beside the pressure ratio and the flow for example a measurement of inlet temperature which help increasing the accuracy of calculating the compressor operating point in its compressor map

4) Fourth category, "Control by neglecting the measurements of flow", where the control achieved by comparing the measurement of pressure ratio to the torque or the rotational speed of the compressor. The good thing in this technique is avoiding any possibility of noise and inaccurate measurement of flow.

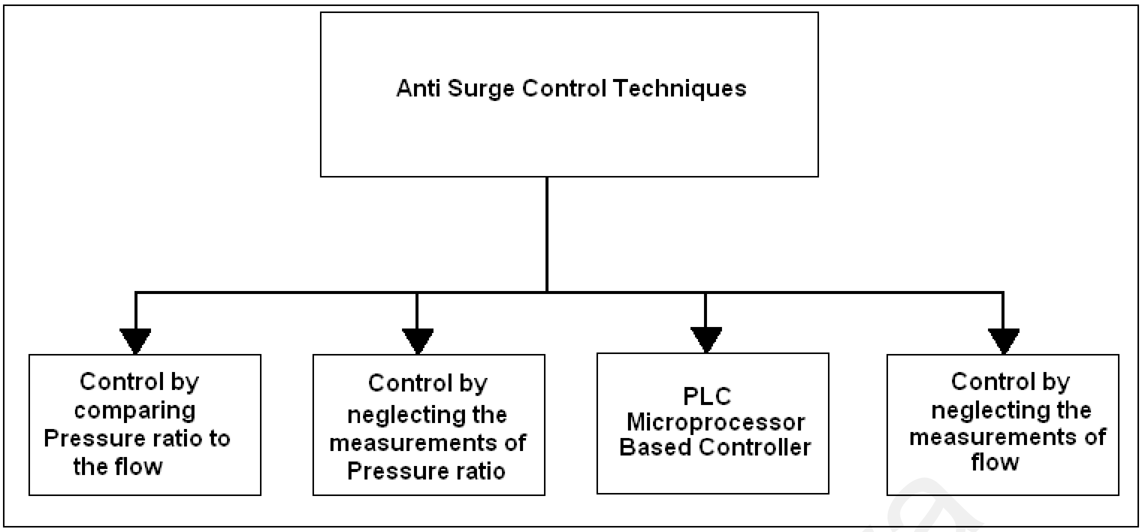

Figure 2.10: Anti Surge Control Techniques

2.4.1 Anti Surge Control and recycling Valve

Recycling valve technique, is the most used way to protect the compressor from surge phenomena the function of the recycling valve is to resend the compressed gas from its outlet to the inlet as shown in figure 2.11 (van Helvoirt, 2007).

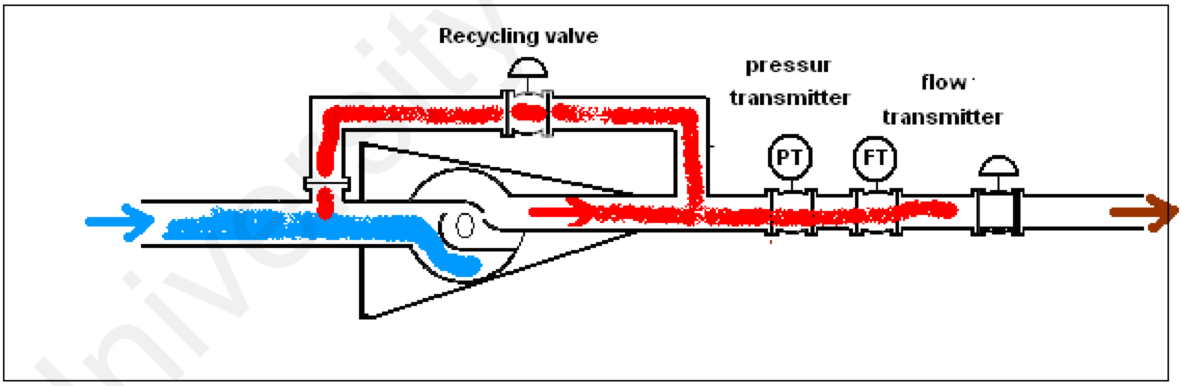

Figure 2.11: avoiding surge phenomena by anti surge control valve the recycle valve should carryout necessary protection during accumulation in the discharge pressure, compressor low flow and any excess in pressure system. The recycle control valve should be quickly opening and closing slowly to avoid the surge as fast as its possible and then maintain the flow stable .

Actually the recycling valve serving three major activities in the compressor

- avoiding the surge
- bring the compressor to the SFEE condition

- keep the compressor running with no down time
- keep the compressor with designed constant pressure

But the disadvantage of the recycling valve is

- lag time to open the valve
- product loss where most of the outlet sent back to the inlet

2.5 Compression Process block diagramme

According to the equation mentioned above the block diagram of this project is shown as in the following figure which explain the open loop transfer function its obvious that its first order system

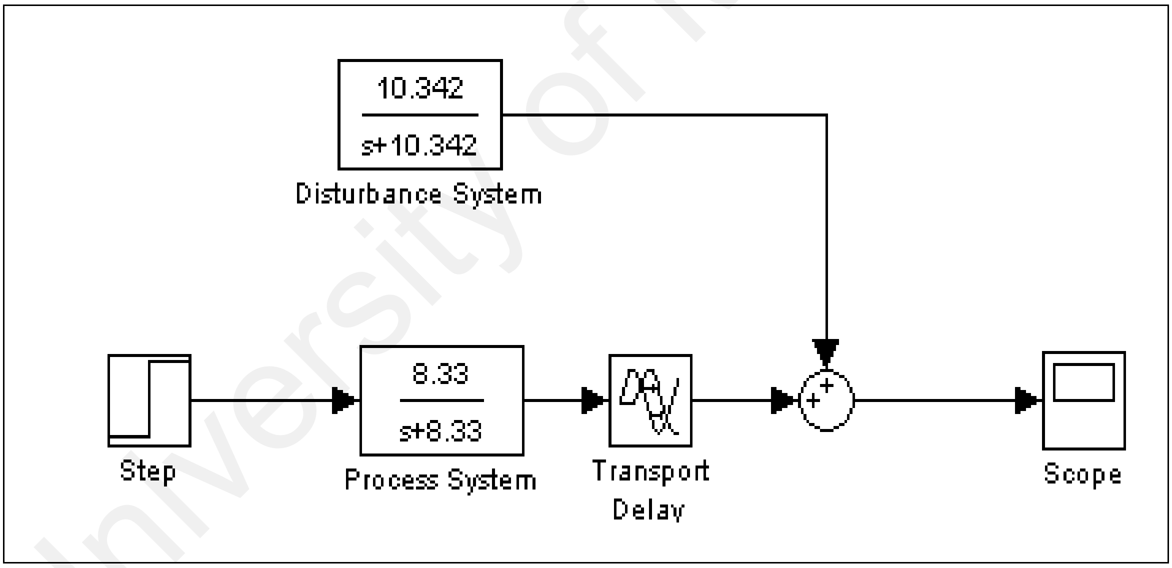

Figure 2.12: Compression processes block diagram

Because its first order system so its controller can be PI but due to the importance of this process PID controller can be designed and this what have been discussed in the following chapter

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter has discussed the methodology simulating the compression system, designing PI/PID, explanation of Smith predictor, design smith predictor. Beginning of the chapter has explained about the research flow chart. Next chapter discussed the time response with the different types of the controllers .Last chapter showing the simulation results using MATLAB /Simulink software.

3.2 Research Flow Chart

Figure 3.1 is shown the Flow chart for the research of this project the procedures of designing from the beginning up to the end of project.

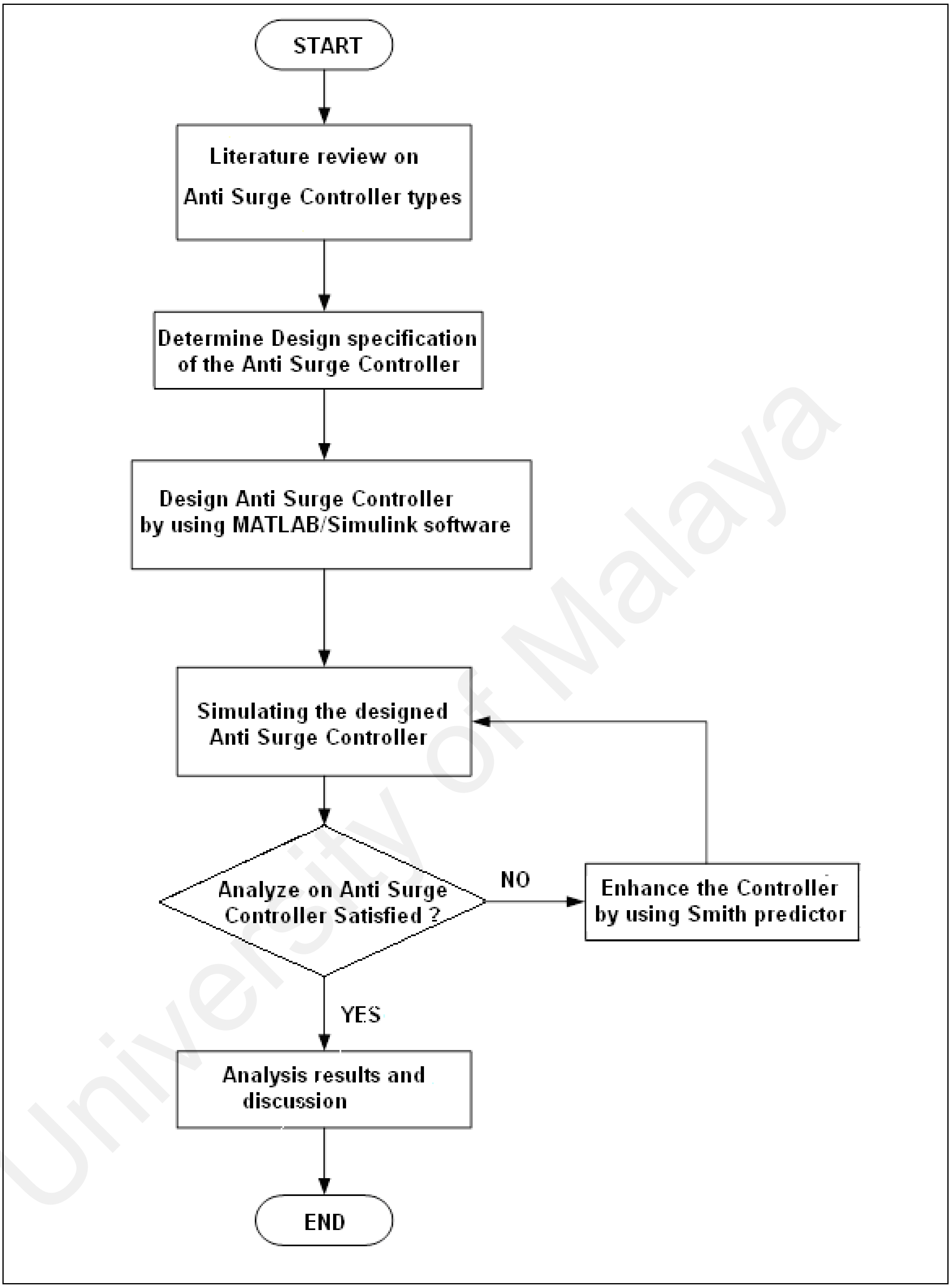

Figure 3.1: Flow chart for Anti Surge Controller Design

3.3 Approximating transfer function of process with delay time

As mentioned in chapter 2 in equation (2.27) that this system has a time delay around 3.3547 ,to design the controller of this system we need to make approximation to the function of the time delay $T(S) = e^{-tS} = e^{-3.357S}$ so this equation needs to be approximated because the MATLAB cannot deal with such that equation especially for automatic tuning of the PI / PID controllers hence Taylor series is the best way to break down this equation (M.Vajta,2000)

So e^{-tS} can be rewired as $$e^{-tS} = \frac{1}{e^{-tS}} = \frac{1}{1 + \frac{tS}{1} + \frac{(tS)^2}{4} + \frac{(tS)^k}{k!}} \tag{3.1}$$

Sometimes it's good to divided this value between the dominator and the nominator so according to Taylor series expansion for e^{-tS} results in

$$e^{-tS} = \frac{e^{\frac{-tS}{2}}}{e^{\frac{tS}{2}}} = \frac{1 - \frac{t/2S}{1} + \frac{(t/2S)^2}{4} + \frac{(-t/2S)^k}{k!}}{1 + \frac{t/2S}{1} + \frac{(t/2S)^2}{4} + \frac{(t/2S)^k}{k!}} \tag{3.2}$$

Based on Padé method there are certain ways which represent the delay function depends on the value of the time delay 3.357 we can select the value of K as following

when K=1

$$e^{-tS} = \frac{e^{\frac{-tS}{2}}}{e^{\frac{tS}{2}}} \approx \frac{1 - t/2S}{1 + t/2S} \tag{3.3}$$

But due to the value of the time delay and because the system is first order the delay time function can be expressed as

$$e^{-tS} \approx \frac{1}{e^{\frac{tS}{2}}} = \frac{1}{1 + t/2S} \tag{3.4}$$

and this expression is very common according to the Padé approximation and the behavior of the system with this approximation is strongly acceptable

$$e^{-3.3547S} = \frac{e^{\frac{-3.3.547S}{2}}}{e^{\frac{3.3547S}{2}}} \approx \frac{1}{1.675S + 1} \tag{3.5}$$

,then after getting this approximation and before designing PI/PID controllers comparison between the behavior and performance of the original transfer function and the approximation can be implemented then this PI/PID controller designed and enhanced by using Smith predictor

3.3.1 Transfer function of the compression system before the approximation

As mentioned in equation (2.27) f the transfer function for this system before the approximation is shown in figure 3.2

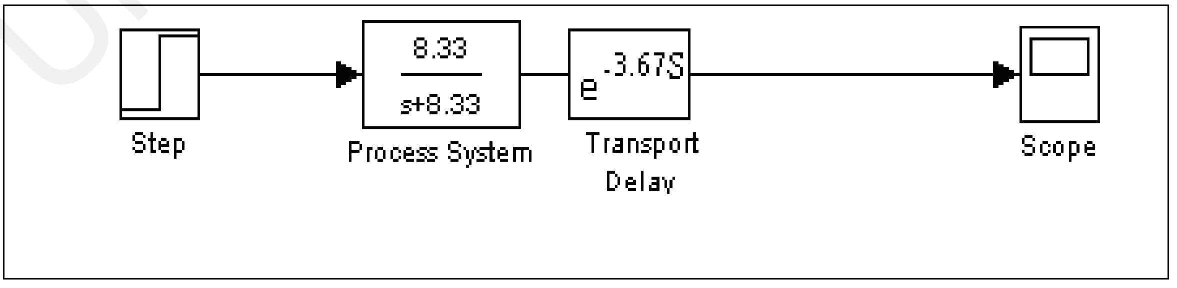

Figure 3.2: Process Transfer Function before approximation

The behavior of this system is sown in figure 3.3

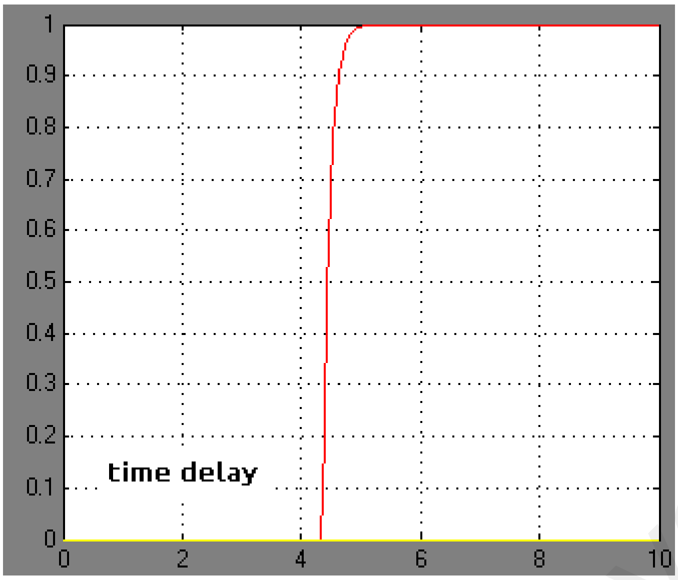

Figure 3.3: Process system behavior before approximation

In figure 3.3 the behavior before approximation shows the time delay is around 4.5 s which is around 1 s delay has been added to the transport time delay and the system will not reach to set point before 4.5 s

3.3.2 Transfer function of the compression system after the approximation

As mentioned in equation (3.5) f the transfer function for this system after the approximation is shown in figure 3.4

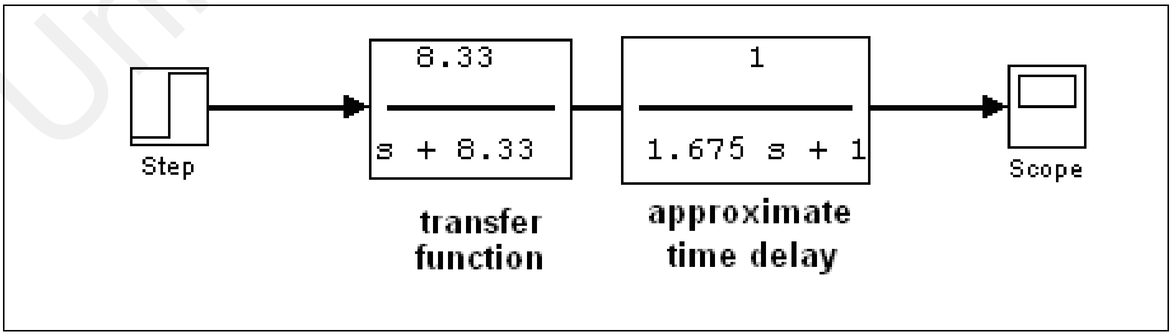

Figure 3.4: the transfer function after approximation

And here is the system behavior as shown in the in figure 3.5 where the process will reach to the 90% of the set point only after 5 s

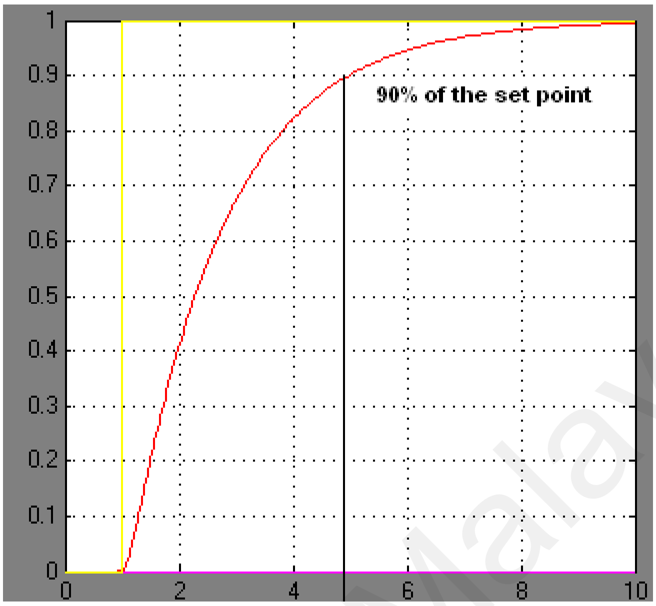

Figure 3.5: system behavior after approximation

From the above figure it's very obvious that the delay time is implemented in the rise time and comparing to figure 3.4 its clear that the approximation is acceptable

3.4 Designing the controller

To design the controller of this system the approximate system has been taken for the designing purpose that because

- the design is done based on number of poles and zeros
- the auto tuning of the PI cannot achieve based on the exact system

So only the approximation transfer function has been manipulated in this project

3.4.1 Designing the PI controller with approximation

The auto tuning of the PI controller is based on internal model control tuning .and these PI values have been gotten

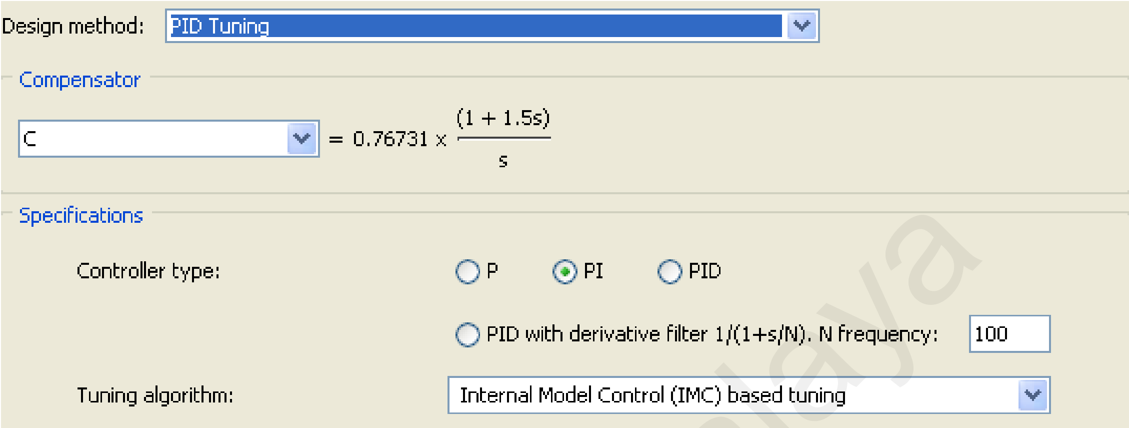

Figure 3.6: Auto PI tuning

And if we want to implement these values of the PI tuning according to the following figure

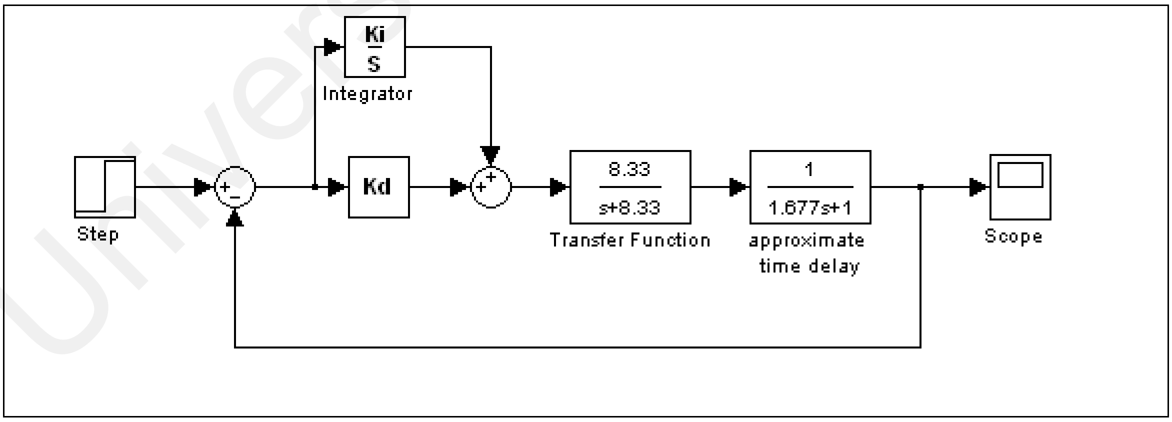

Figure 3.7: PI controller Block diagram with approximate time delay

Its clear that P controller is in parallel with the I controller and this can be calculated to find the values of Kp and Ki as following

$$Kp + \frac{Ki}{S} = 0.76731 \times \frac{(1+1.5S)}{S} \tag{3.6}$$

$$\frac{KpS + Ki}{S} = 0.76731 \times \frac{(1+1.5S)}{S} \tag{3.7}$$

$$Ki \frac{(1+\frac{Kp}{Ki}S)}{S} = 0.76731 \times \frac{(1+1.5S)}{S} \tag{3.8}$$

$$\text{so } Ki = 0.76731 \text{ and } \because \frac{Kp}{Ki} = 1.5p \text{ so } Kp = 1.14465 \tag{3.9}$$

and the response of the as shown in Figure 3.8 time response without PI

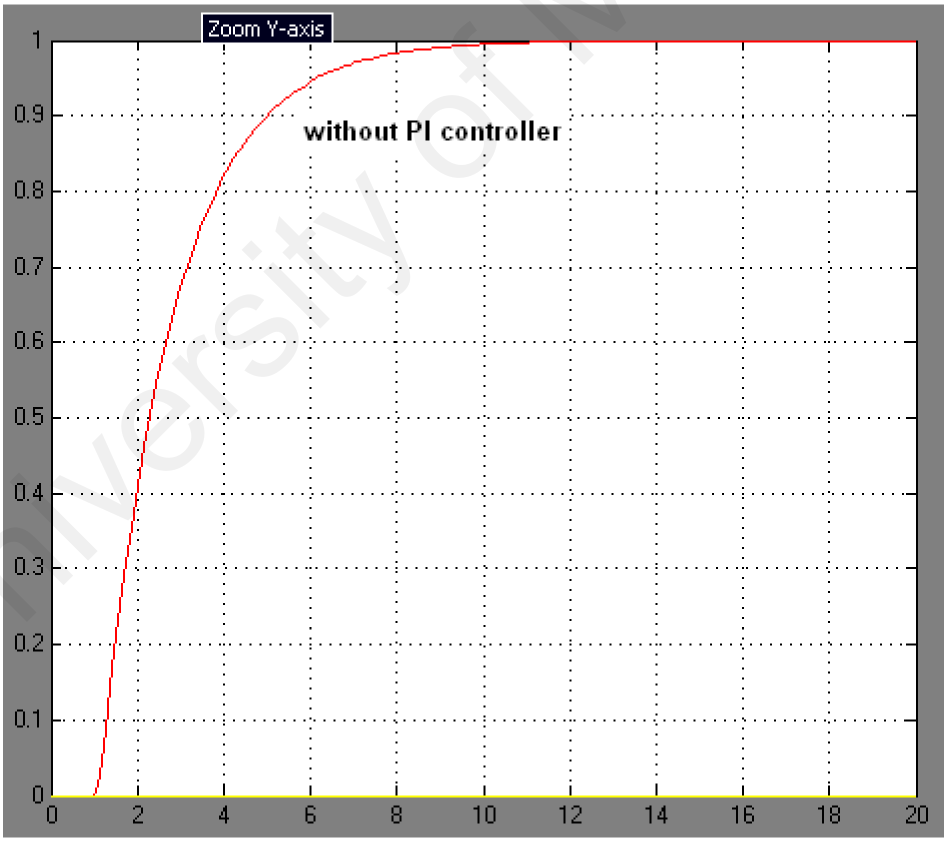

Figure 3.8: time response without PI controller toke 10 s to reach to the set point And after adding the PI controller to the system there is around 4 s of enhancement

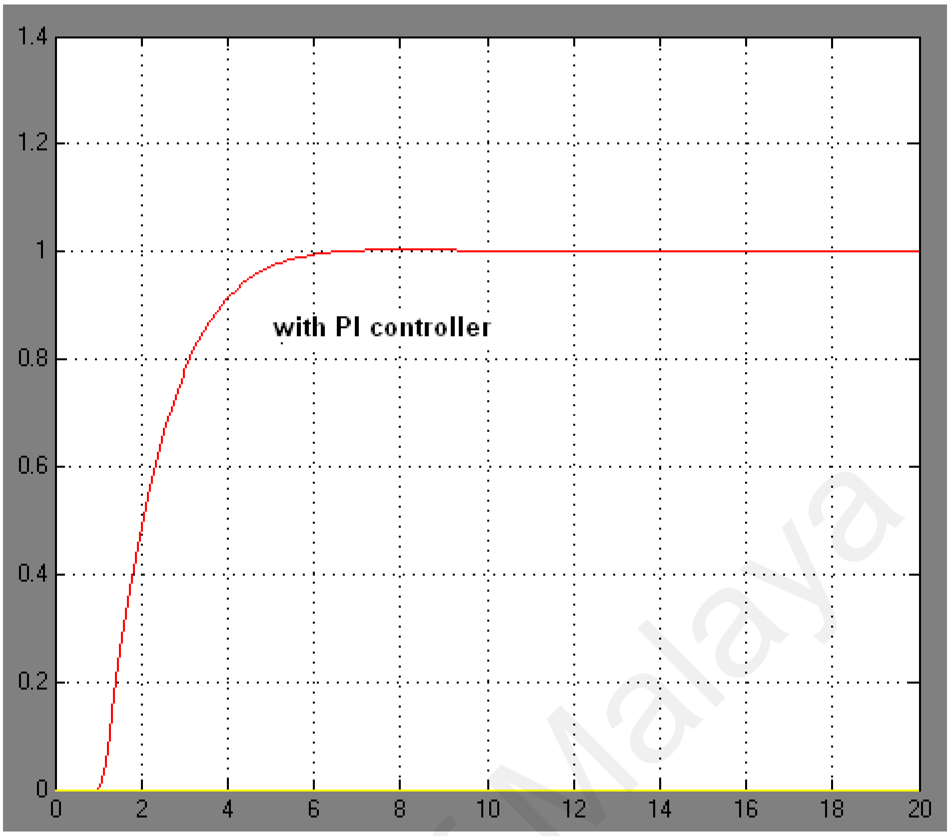

Figure 3.9: with PI controller got good time response after only 6 s reaching to the set point

So its clear that the PI value as in the following table

Table 3.1: PI values based on internal model control auto tuning with Padé approximation

Items	Value
Proportional band Kp	0.7631
Integral band Ki	1.14465

3.4.1.1 Development of the PI controller without approximation

As mentioned the designed PI controller above was based on Padé approximation and the PI values determined above are suitable for the approximated system but this PI will be used for the exact system then these PI values have been developed by try and error until reaching to the appropriate PI values figure 3.10 shows the appropriate values of the PI

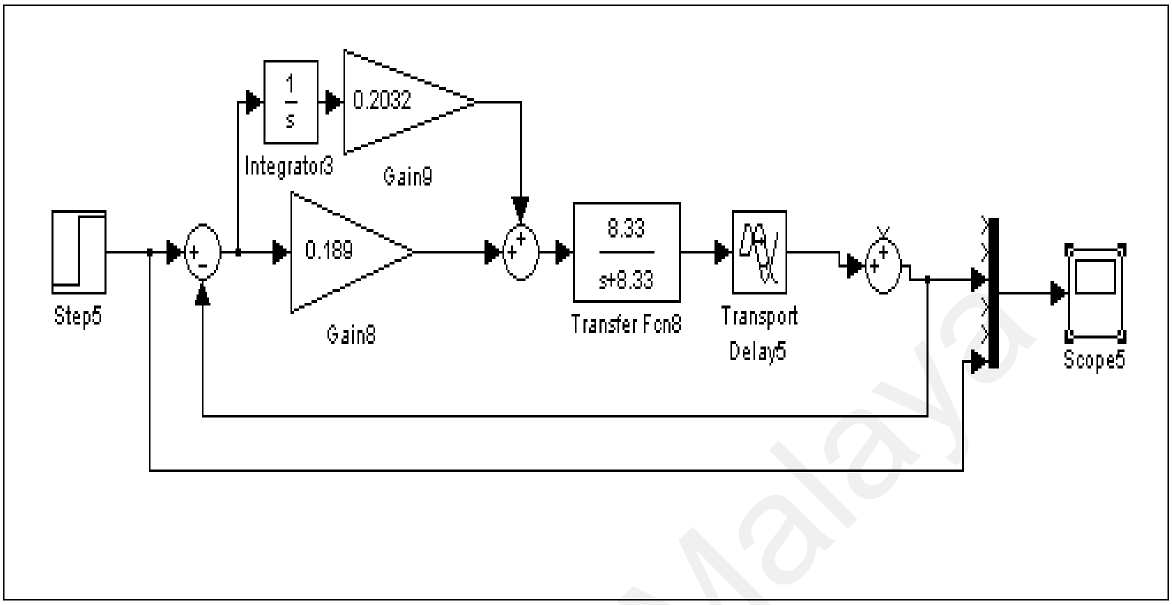

Figure 3.10: developed PI control for the exact system

And the time response of the exact system with the developed PI values is shown in the following figure

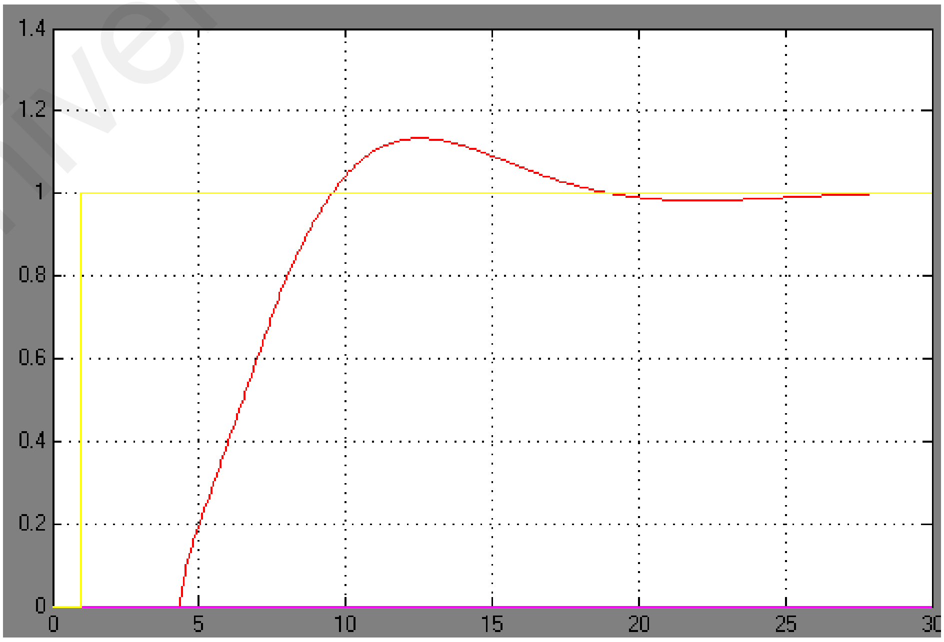

Figure 3.11: time response with the developed PI controller

3.4.2 Designing the PID controller with approximation

According to the figure 3.12 shows bellow

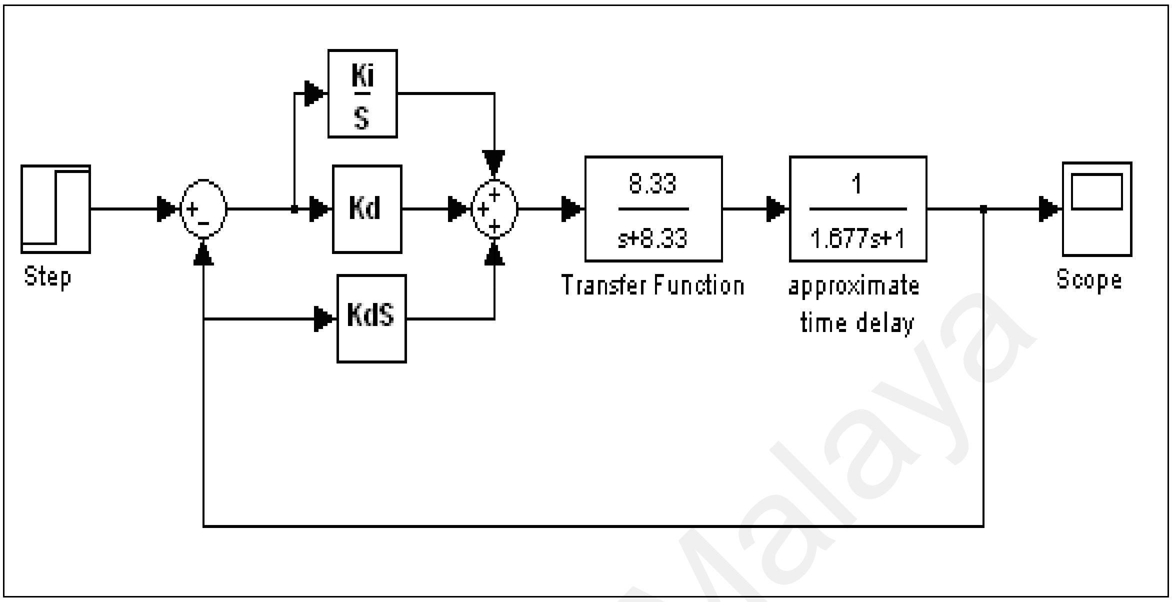

Figure 3.12: PID controller with approximate time delay

PID controller value obtained based on internal model control tuning was as following

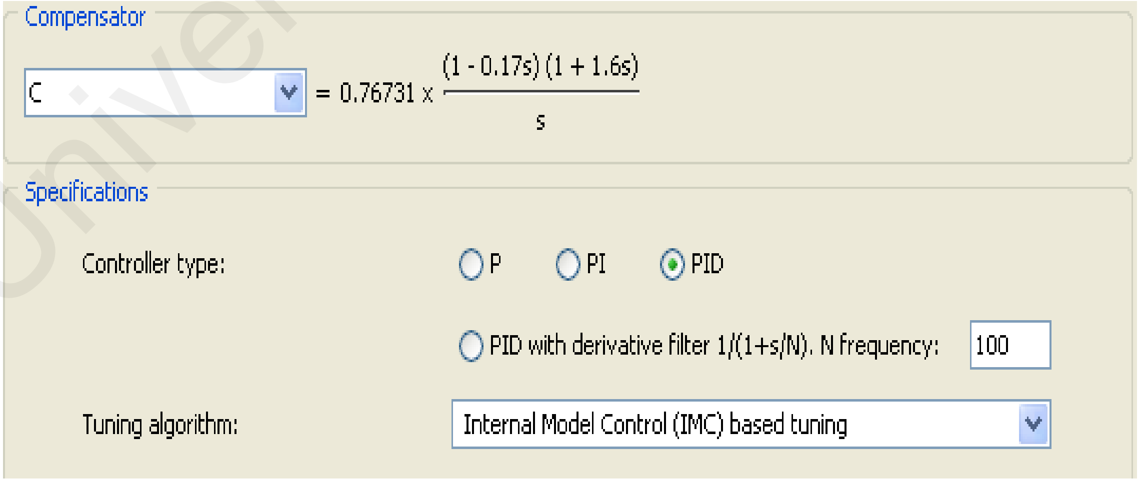

Figure 3.13: Auto PID tuning

And by analyzing this equation with PID equation

$$Kp + \frac{Ki}{S} + Kd\ S = 0.76731 \times \frac{(1 - 0.17S)(1 + 1.6S)}{S} \tag{3.10}$$

$$Kp + \frac{Ki}{S} + Kd\ S = 0.76731 \times \frac{(1 + 1.43S - 0.272S\ \ )}{S} \tag{3.11}$$

$$Kp + \frac{Ki}{S} + Kd\ S = \times \frac{(0.76731 + 1.2276S - 0.2087S^2)}{S} \tag{3.12}$$

$$Kp + \frac{Ki}{S} + Kd\ S = 1.2276 + \frac{0.76731}{S} - 0.2087S \tag{3.13}$$

$$Kp = 1.2276 \tag{3.14}$$

$$Ki = 0.76731 \tag{3.15}$$

$$Kd = -0.2087S \tag{3.16}$$

and the response of the system with the controller and without the controller can be jus like the following figures

Figure 3.14: time response without PID controller toke 10 s to reach to the set point And after adding the PID controller around 3s improvement is gotten

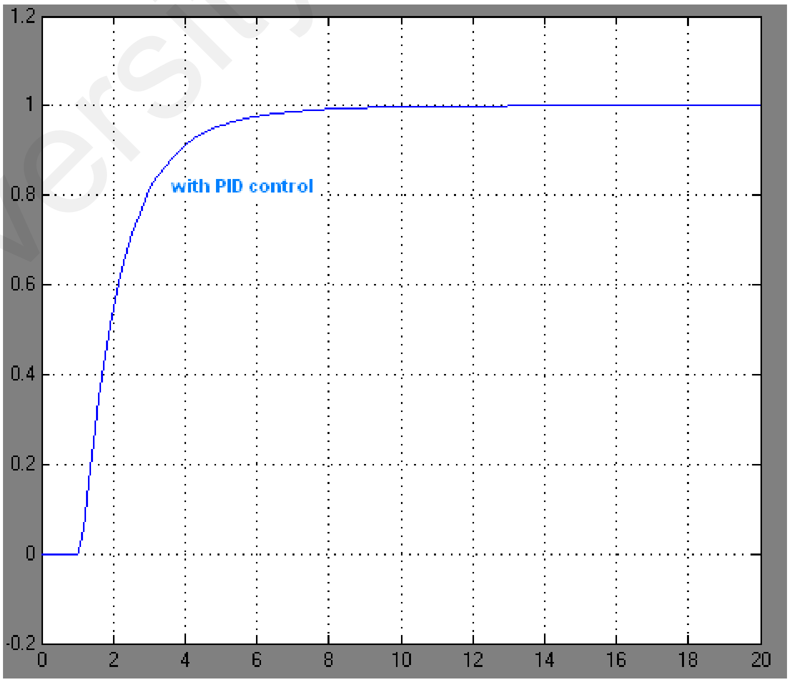

Figure 3.15: with PID controller got good time response after only 7 s reaching to the set point but there is a negative response because Kd is negative

But in this time response -0.2 value is shown which means inverse response in the graph that because the Kd is negative which is -0.2087 so to eliminate this its better to make Kd positive value so Kd=0.2087 by this value the following time response can be obtained as shown in figure 3.16

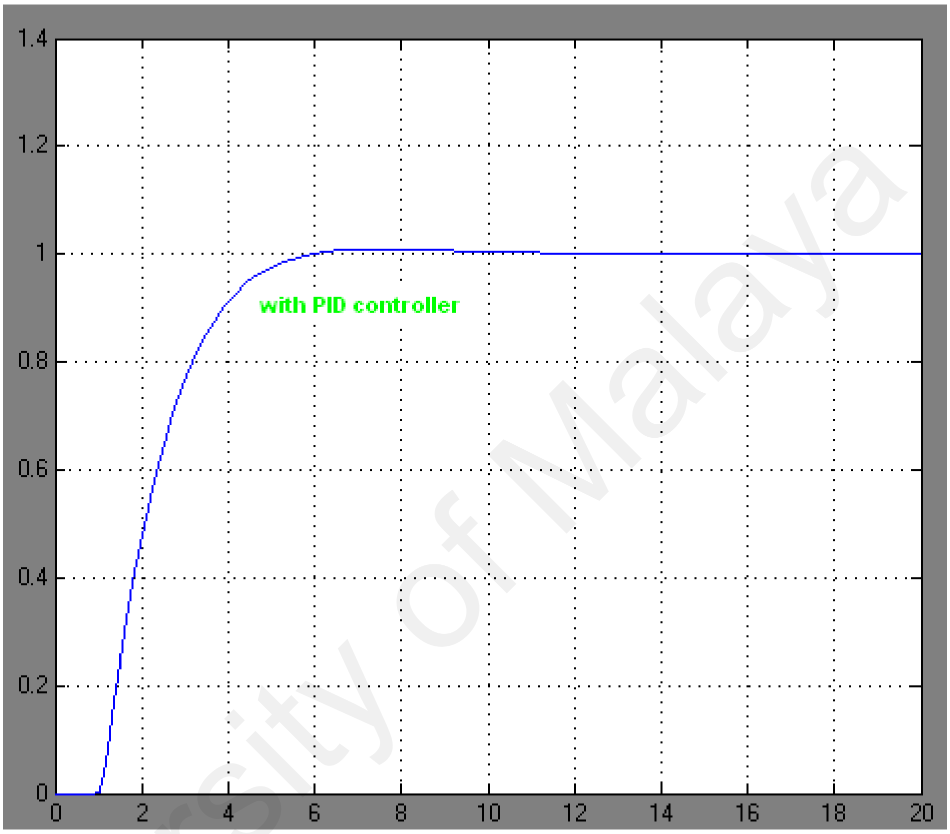

Figure 3.16: with PID controller got good time response after 7 s reaching to the set point with positive Kd value no inverse response

Its clear that almost there is no deference between the PI and PID controller and that's because the system is first order where all first order systems needs PI controller only and the second order systems need PID controller. The values of the PID controller are as shown in the following table

Table 3.2: PID values based on internal modern controller auto tuning with Padé approximation

Materials	Properties
Kp	1.2276
Ki	0.7673
Kd	0.2087

3.4.2.1 Development of PI D controller without approximation

As mentioned the designed PID controller above was based on Padé approximation and the PID values determined above are suitable for the approximated system but this PID controller is used for the exact system then by try and error until reaching to the appropriate PID values figure 3.17 shows the appropriate values of the PID

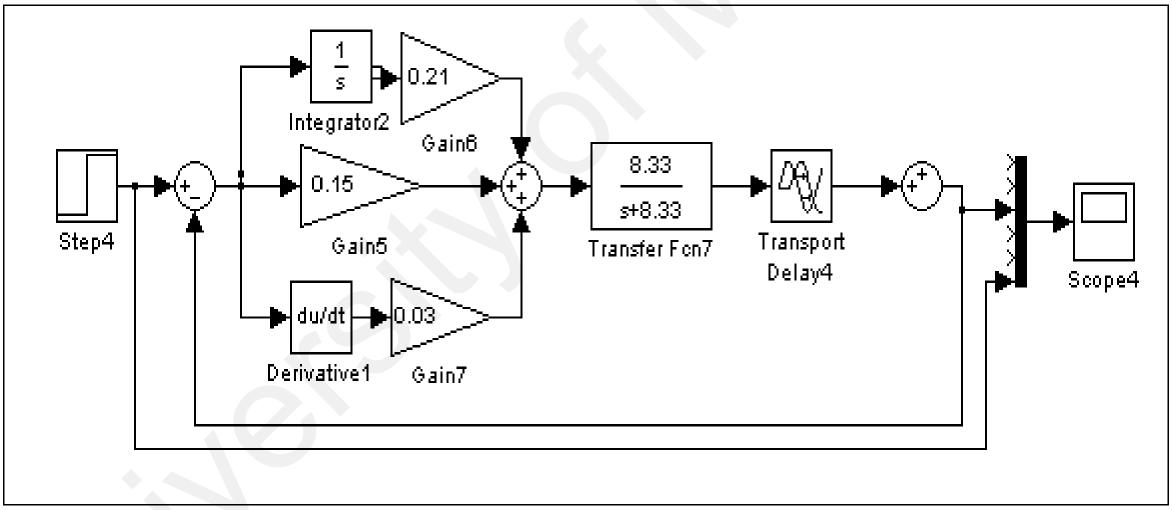

Figure 3.17: developed PID control for the exact system

And the time response of the exact system with delved PID is shown in the following figure

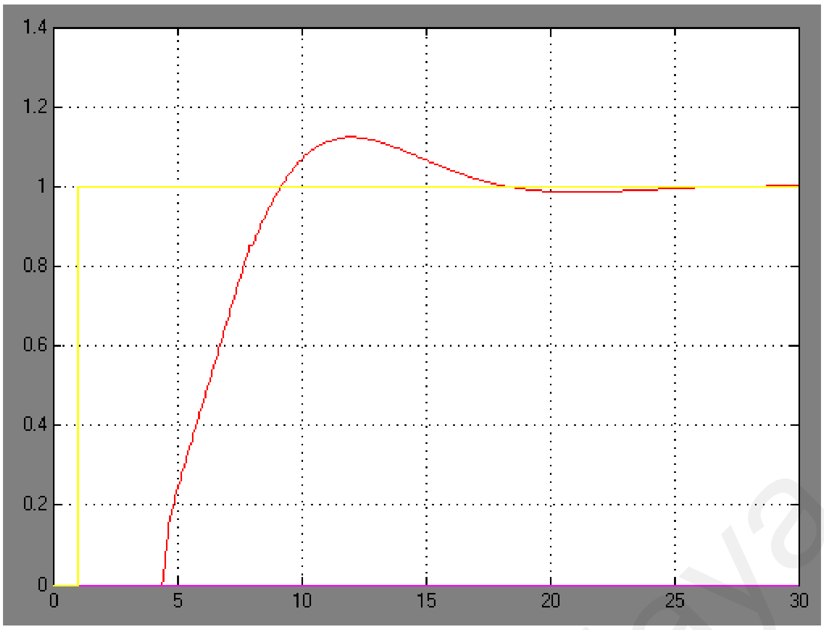

Figure 3.18: time response with the developed PID controller

3.5 Smith Predictor

This section introduces illustration of Smith predictor to solve the delay time for the PI / PID controllers. Figure 3.19 shown the basic block diagram configuration for the Smith Predictor the idea of the Smith Predictor is to develop a model $G_m(S)$ to predict the response of process with its delay time then by comparing the output of actual process with a prediction model $G_m(S)$

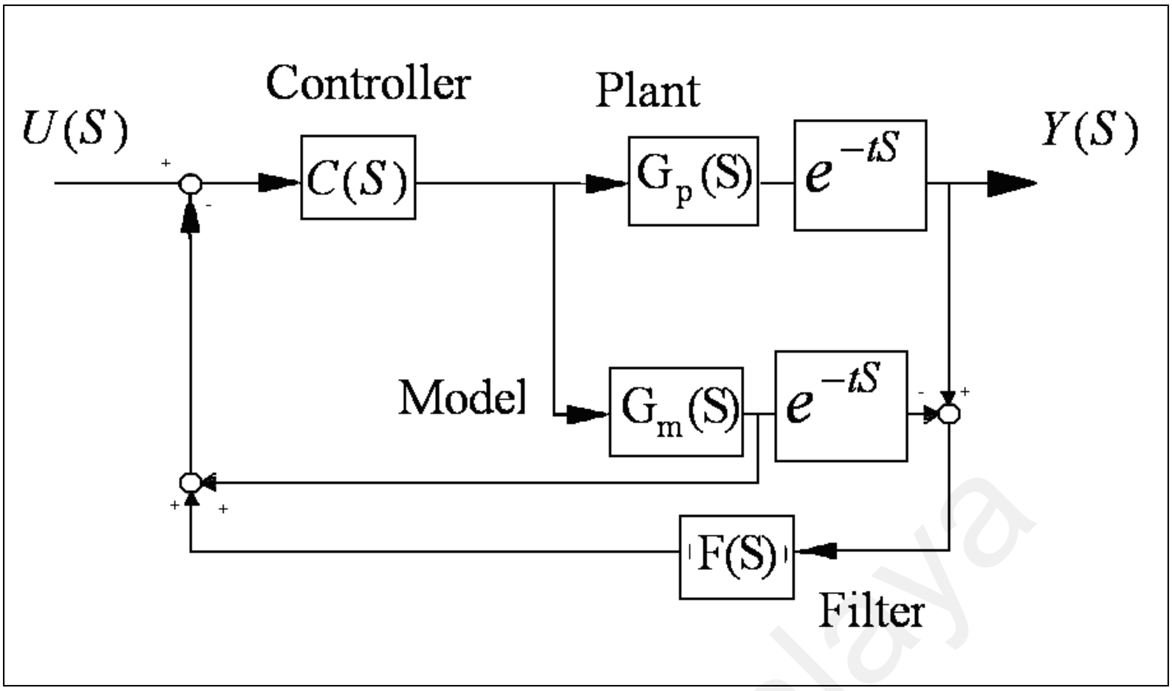

Figure 3.19: Smith predictor block diagram

(Abdelkader Maddi* and Abderrezak Guessoum,2015), (Douglas J. Cooper,2005)

Then the deference between actual system to the modeled system is sent to filter to enhance the prediction designing

3.5.1 Development of Smith predictor with PI Controller

Development of Smith Predictor with PI controller is shown in figure 3.20 where the developed PI controller values are enhanced by try and error to meet new setting of the system after adding the Smith predictor

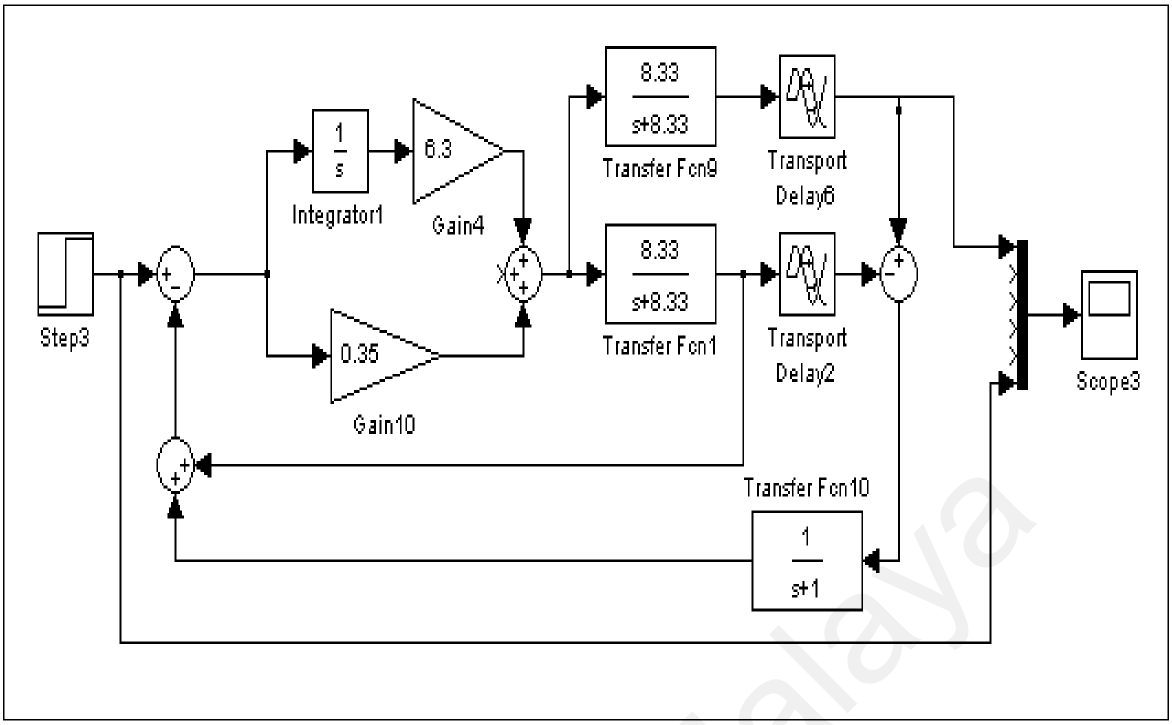

Figure 3.20: developed PI controller with Smith predictor

The value of the PI parameters are modified by try and error until reaching to the suitable values as mentioned in the table (3.3)

Table 3.3: PI values for the system with Smith Predictor set by try and error .

Items	Value
Proportional band Kp	6.3
Integral band Ki	0.35

And the time response of the PI controller developed and enhanced by using Smith predictor method is shown in the following figure

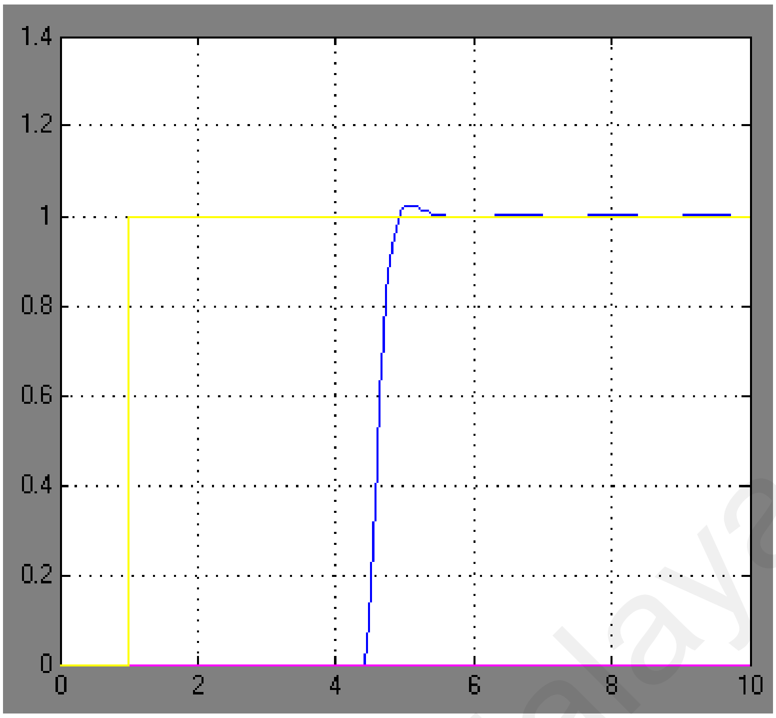

Figure 3.21: time response of the PI controller developed and enhanced by Smith predictor

3.5.2 Development of Smith predictor with PID Controller

As shown in figure 3.22 from the previous process system and its developed PID controller let use P controller gain and increase it as much as higher than designed with in allowable response., so P gain values will be multiplied by 10 slightly change of 0.5 will be made until getting the optimized time response for the gain of the Integral and derivative values slightly change of 0.2 will be made until getting the optimized time response

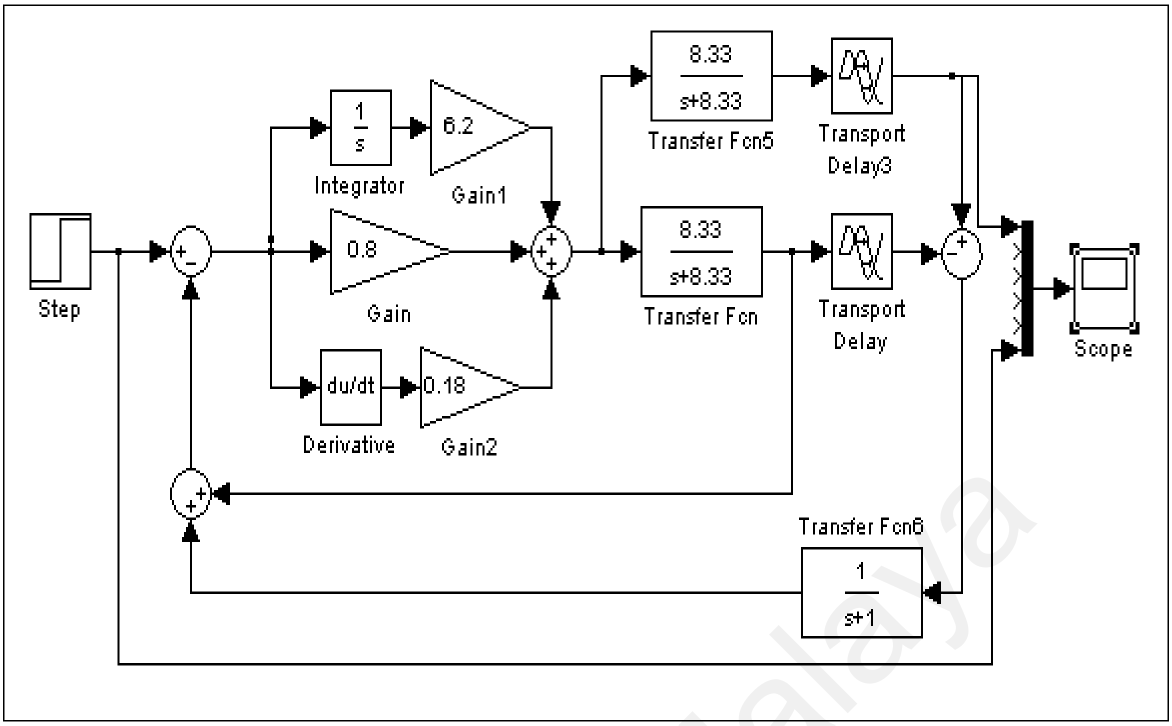

Figure 3.22: developed PID controller with Smith predictor

on the other hand, as, for perfect time delay controller for the Smith predictor necessitates a well done model, whereas real perfect models are never obtained , so cautious is required for choosing the parameters of the controller so large enough of the integral parameters of the controller have been chosen to achieve better performance as much as possible than alone feedback control, and to be taken in account that too large gains parameter could cause unwanted deterioration to the performance due to mismatch plant/model systems by applying these technique the PID values are achieved as in table (3.4)

Table 3.4: PID values with Smith Predictor set by try and error.

Materials	Properties
Kp	6.2
Ki	0.8
Kd	0.18

And the achieved time response for the developed PID controller with smith predictor as shown in the following Figure When all the

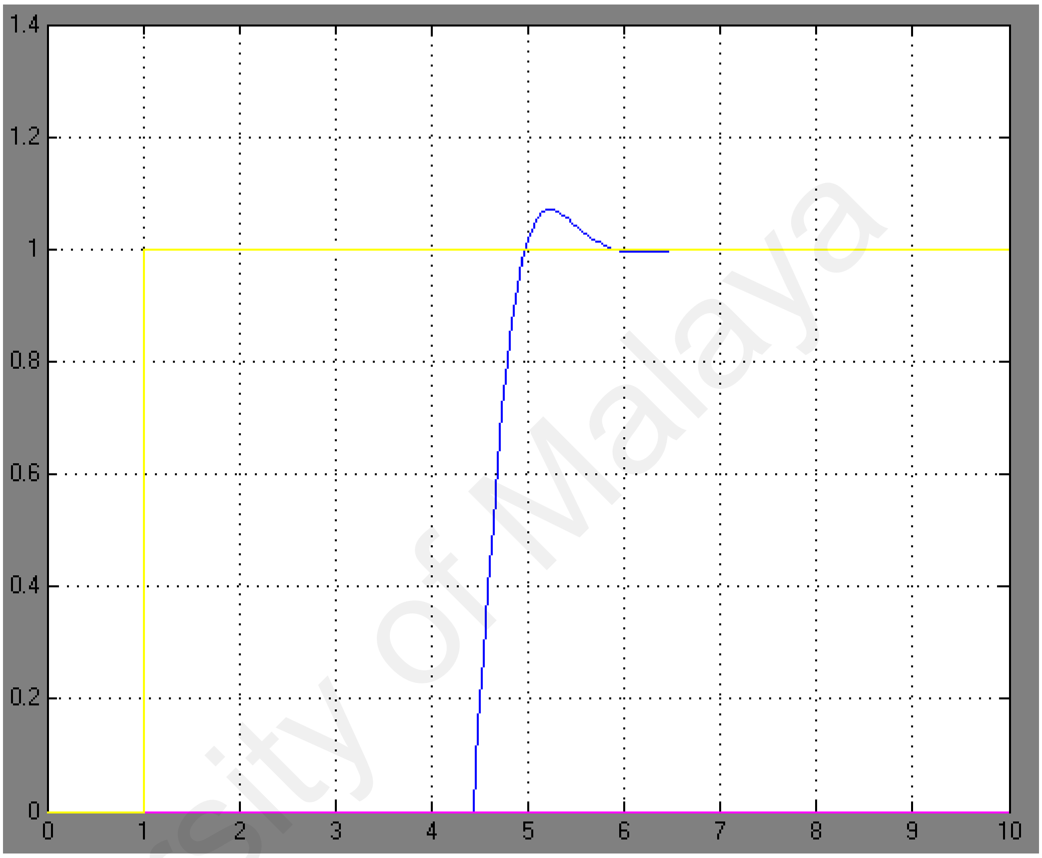

Figure 3.23: time response of PID controller enhanced by Smith Predictor

3.6 Simulation Settings

A few blocks diagrams are built in the Simulink software as shown in figure 3.24 are available for the designing of any controllers based on the nature of the system and then these controllers can be tuned by Simulink software automatically. A time response bode diagram and Nyquist diagram are available to study the system and that's what this research project has studied in chapter 5.

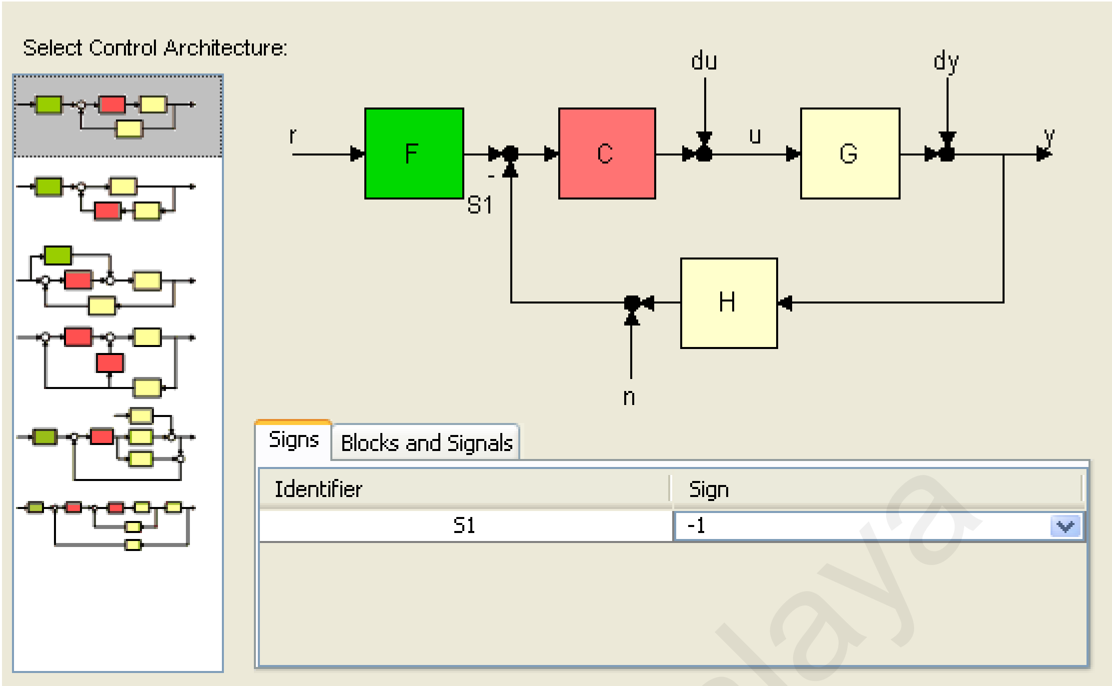

Figure 3.24: the selected control architecture where H=1 and F=1and dy=du =n =0.

3.7 Summary

The disquisition of this chapter was on the approach and methodology for this research project. Starting this chapter by explaining the flow chart of the methodology which has been used .Then defining the PI / PID parameters of the controller for the approximated system based on internal mode control auto tuning. Next, the PI /PID parameter have been tuned by try and error to fit the exact system followed by setting the Smith predictor for the system finally, all the PI /PID parameters are optimized to fit the system requirements after developing of the Smith predictor is done . The design and development have been done by using MATLAB / Simulink software.

CHAPTER 4: RESULT AND DISCUSSIONS

4.1 Introduction

This chapter discussed all the simulation results of PI / PID controller which have been simulated using MATLAB / Simulink software and the simulation result based on the developed PI/ PID controller and enhanced controller by Smith predictor. The results have been studied, analyzed and compared to find out the obtained improvement of the control system.

4.2 Analysis and Discussions of PI Controller.

From Figure 4.1optimized PI controller Block shows the optimized values of the PI gain as mentioned in table (4.1)

Table 4.1: PI values for Optimized Controller without Smith Predictor

Items	Value
Proportional band Kp	0.189
Integral band Ki	0.2032

But for more accuracy new PI values have changed and its time response of the system are analyzed and studied.

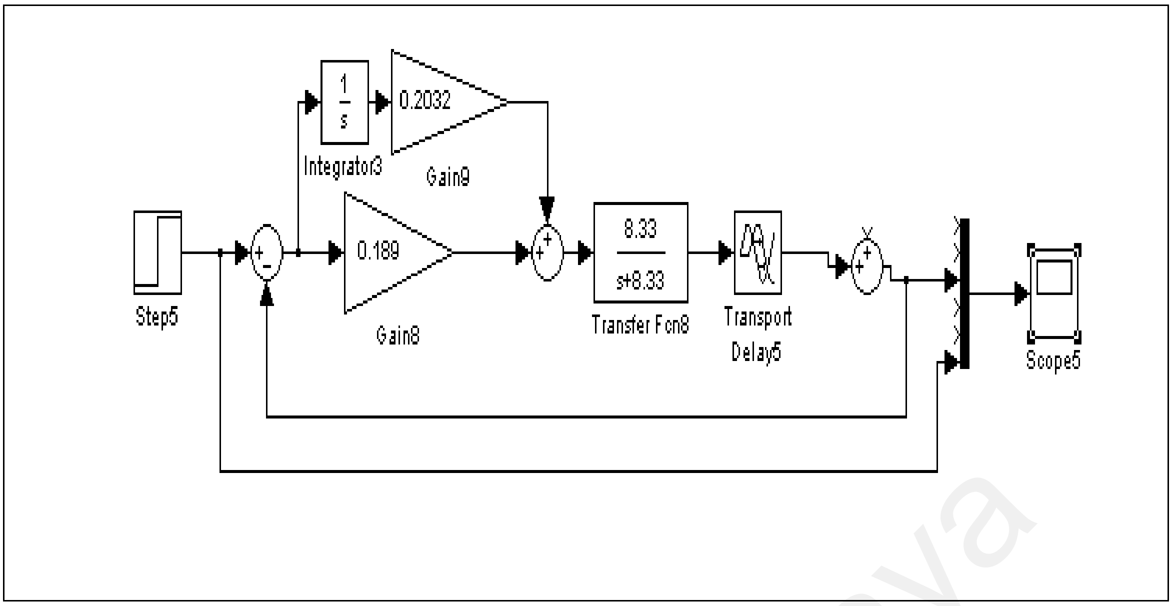

Figure 4.1: Optimized PI controller Block Diagram

4.2.1 PI controller's gain Kp=0.5* 0.189, Kp=1.5 * 0.189and Kp=0.189

Graph for time response vs different values of Kp is shown in Figure 4.2 From the plotted graph, stability of the system is increase with the change of Kp more or less than 0.189 . from this graph the following date are obtained as mentioned in table (4.2)

Table 4.2: System response based on PI Controller with different Kp values

	Kp=0.5*0.189	**Kp=01.5*0.189**	**Kp=0.189**
Rise time	7.474	6.44	7.164
Settling time	16.7	13.5	14.1
Notes	slowest	Fastest but noisy	The best response

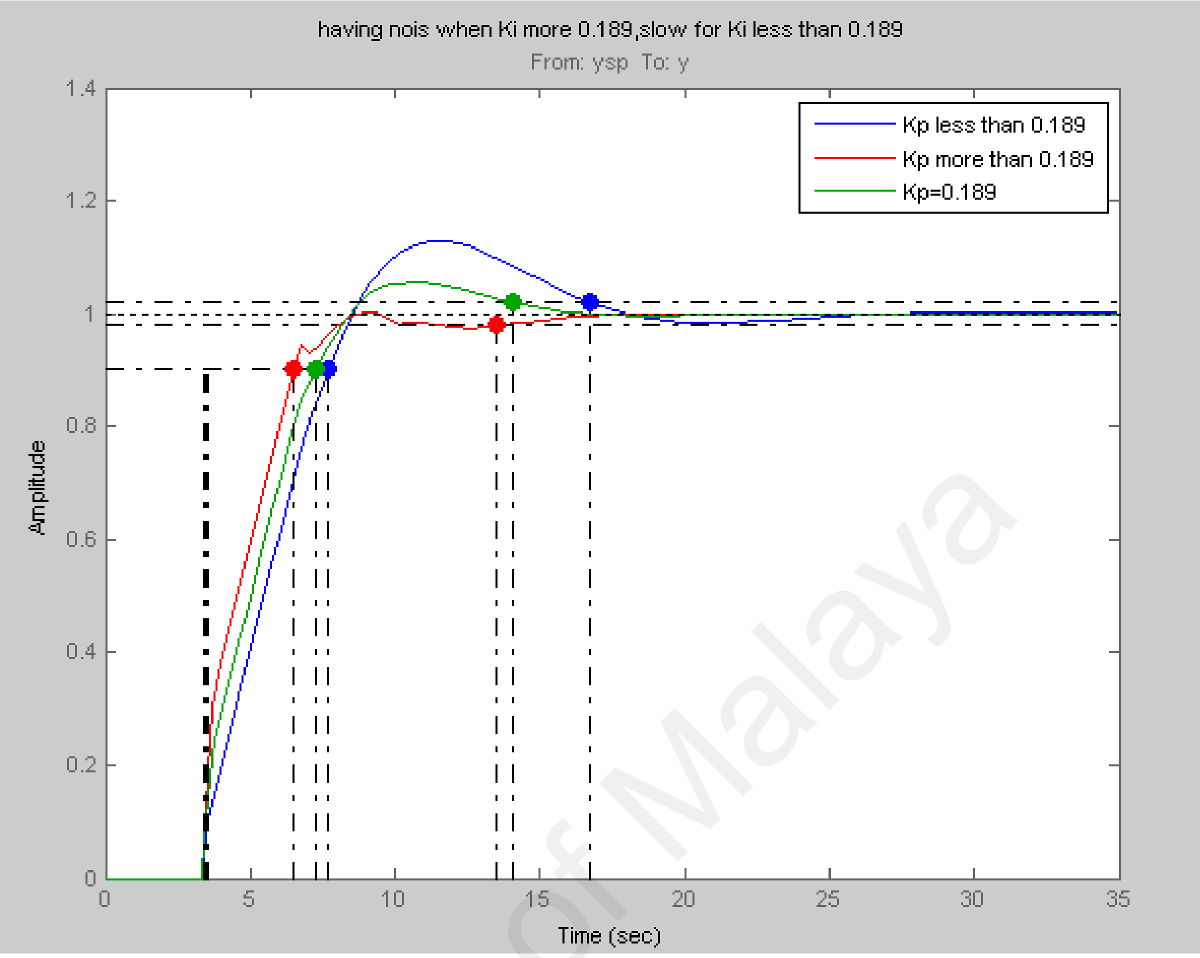

Figure 4.2: Optimizing PI Controller shows the Plot having noise when Kp more than 0.189,slow for Kp less than 0.189

From Figure 4.2, fast response when Kp =1.5*0.189 but the response has noise in the beginning which is not good for the process while the response when Kp=0.5*0.189 is slow and that's what the process doesn't want lastly when the Kp=0.189 the best response has been optimized.

4.2.2 PI controller's gain Ki=0.5* 0.2032, Kp=1.5 * 0.2032and Kp=0.2032

Its obviously shown in Figure 4.3 time response vs different values of Ki the stability of the system is increase with the change of Ki more or less than 0.2032 as shown From the plotted graph, next date are obtained from this graph

Table 4.3: System response based on PI Controller with different Ki values

	Ki=0.5*0.189	**Ki=1.5*0.189**	**Ki=0.189**
Rise time	20.25	5.8	7.26
Settling time	33.8	30.8	14.1
Notes	Slow rise time	Slow silting time	The best response

And here are the time response based on different

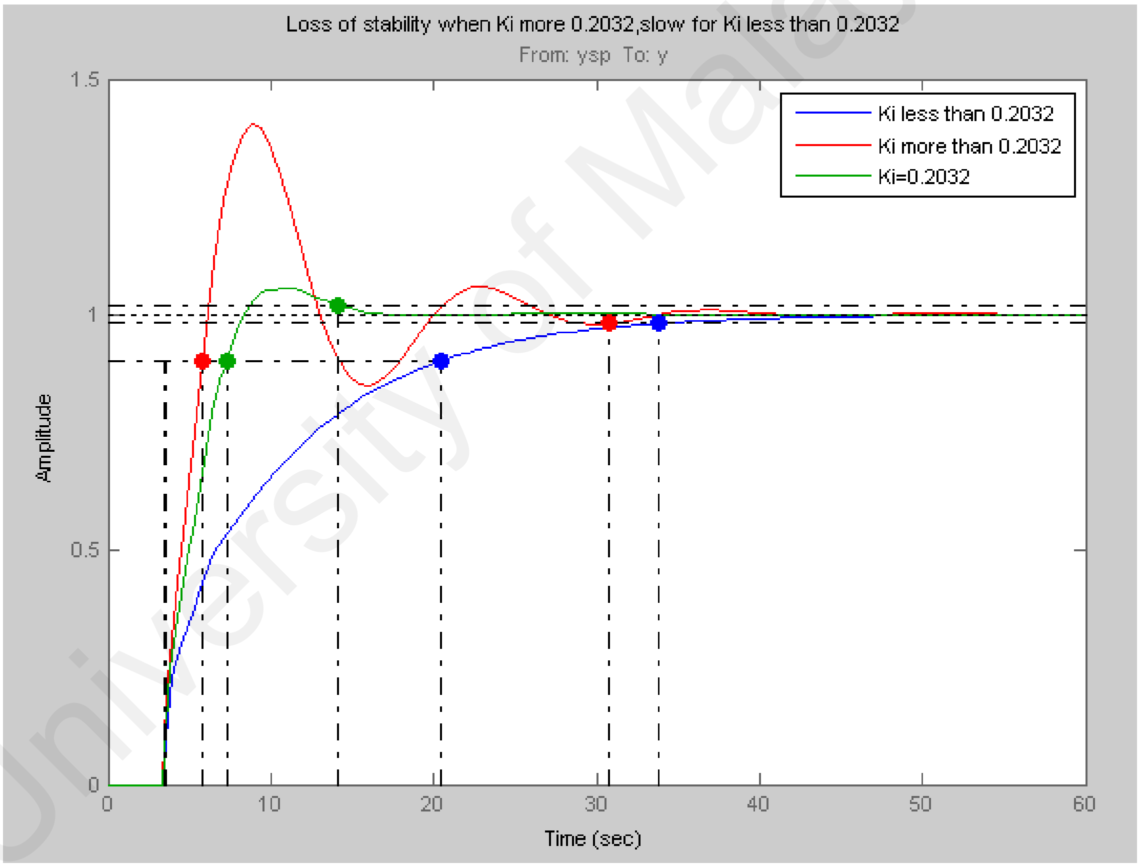

Figure 4.3: Optimizing PI Controller Plot shows Loss of stability when Ki more than 0.2032,slow for Ki less than 0.2032

the response when Ki=0.5*0.2032 is slow as shown From Figure 4.3 ,fast response when Ki =1.5*0.2032 but the response unstable for longer time not while when the Ki=0.2032 the best response has been optimized.

4.3 Analysis and Discussions of PID Controller.

The designed PID controller of the anti surge control system is shown in Figure 4.4

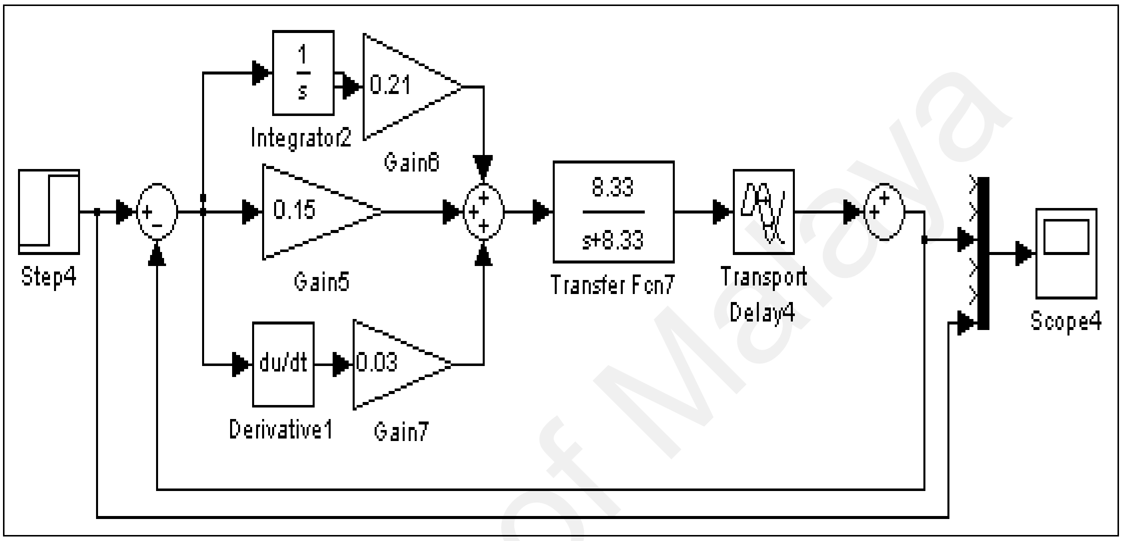

Figure 4.4: Optimized PID controller Block Diagram

The PID block diagram shows the optimized values of the PID gain as mentioned in table (4.4)

Table 4.4: PID values for Optimized Controller without Smith Predictor

Items	Value
Proportional band Kp	0.16
Integral band Ki	0.21
Derivative band Kd	0.03

To see the effect of changing PID gains these gains have changed and the system response have been studied as in next section

4.3.1 PID controller's gain Kp=0.5* 0.16, Kp=1.5 * 0.16 and Kp=0.16.

Figure 4.5 shows the effect of changing the Kp values on the system response its obviously that the system is fast when Kp higher than 0.16 but contains noise which is unwanted for critical system and the system response is too slow with big offset when the Kp is less than 0.16.

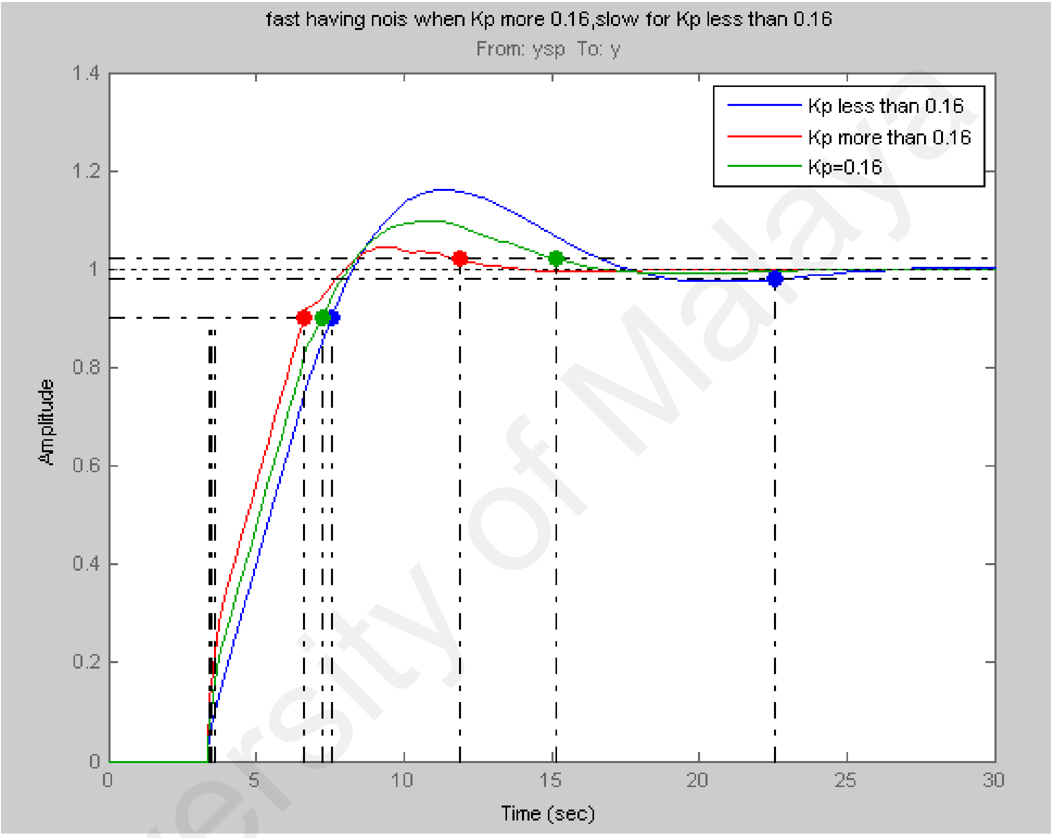

Figure 4.5: Optimizing PID Controller Plot shows fast response but having noise when Kp more than 0.16,slow for Kp less than 0.16.

from this graph above the following date are obtained as mentioned in table (4.5)

Table 4.5: System response based on PID Controller with different Kp values

	Kp=0.5*0.16	Kp=01.5*0.16	Kp=0.16
Rise time	7.3247	6.56	7.1047
Settling time	22.6	11.9	15.2
Notes	slowest	Fastest but noisy	The best response

Table (4.5) shows that the best response obtained is when Kp= 0.16

4.3.2 PID controller's gain Ki=0.5* 0.21, Ki=1.5 * 0.21 and Ki=0.21

The consequence of varying the Ki values shown in Figure 4.6 the system response its clearly that the system is fast when Kp higher than 0.21 but lost the stability and that's should be discarded for critical system and the system response is too slow when the Kp is less than 0.21.

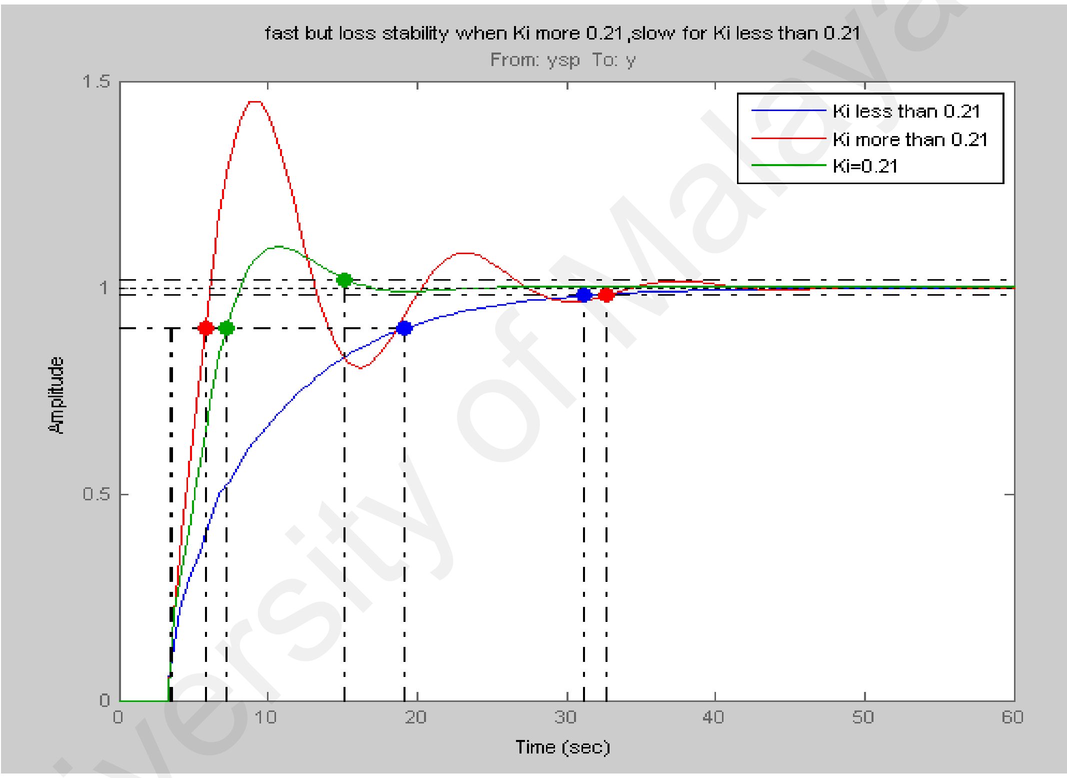

Figure 4.6: Optimizing PID Controller Graph shows fast response but loss stability when Ki more than 0.21,slow for Ki less than 0.21

from this graph above the following date are obtained as mentioned in table (4.6)

Table 4.6: System response based on PID Controller with different Ki values

	Ki=0.5*0.21	**Kp=01.5*0.21**	**Kp=0.21**
Rise time	18.854	5.704	7.104
Settling time	31.2	11.9	32.7
Notes	slowest	Fastest but loss stability	The best response

Table (4.6) explain that the best response obtained is when Kp= 0.21

4.3.3 PID controller's gain Kd=0., Kd=1.5 * 0.03 and Kd=0.03

As shown in Figure 4.7 The variation Kd values is appeared in the system response and its clearly that the system doesn't have major effect of the time response when chagrining Kd but the system will have noise when Kd higher and that's because the system is first order and most of time PI controller is enough for first order systems

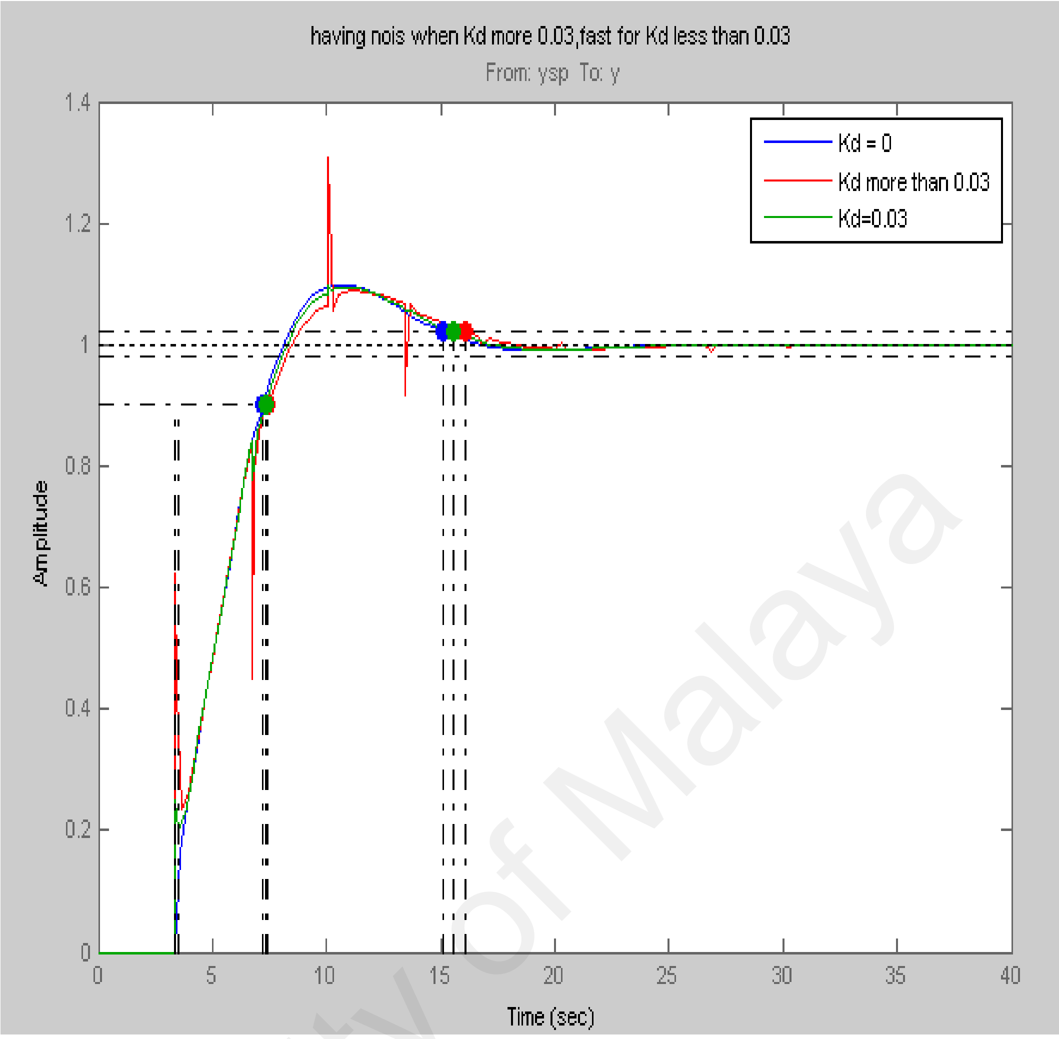

Figure 4.7: Optimizing PID Controller shows time response having noise when Kd more 0.03,fast for Kd less than 0.03

from this graph above the following date are obtained as mentioned in table (4.7)

Table 4.7: System response based on PID Controller with different Kd values

	Ki=0	**Kp=01.5*0.21**	**Kp=0.21**
Rise time	7.06	7.447	7.06
Settling time	15.1	16.1	15.5
Notes	No action	Slow and noise	The best response

Table (4.7) explain that the best response obtained is when Kd= 0.03 even though there is no major effect in general

4.4 Analysis and Discussions of PI Controller and Smith predictor

Figure 4.8 shows the block diagram of the developed PI controller enhanced by Smith Predictor and here the PI values have been optimized to fit the requirement of the new configuration and low pass filter is added to magnify the error and enhance the prediction process so the new PI values from the block diagram bellow are obtained as the following data mentioned in table (4.8)

Table 4.8: PI values for the PI controller enhanced by Smith Pridictor.

Items	Value
Proportional band Kp	6.3
Integral band Ki	0.35

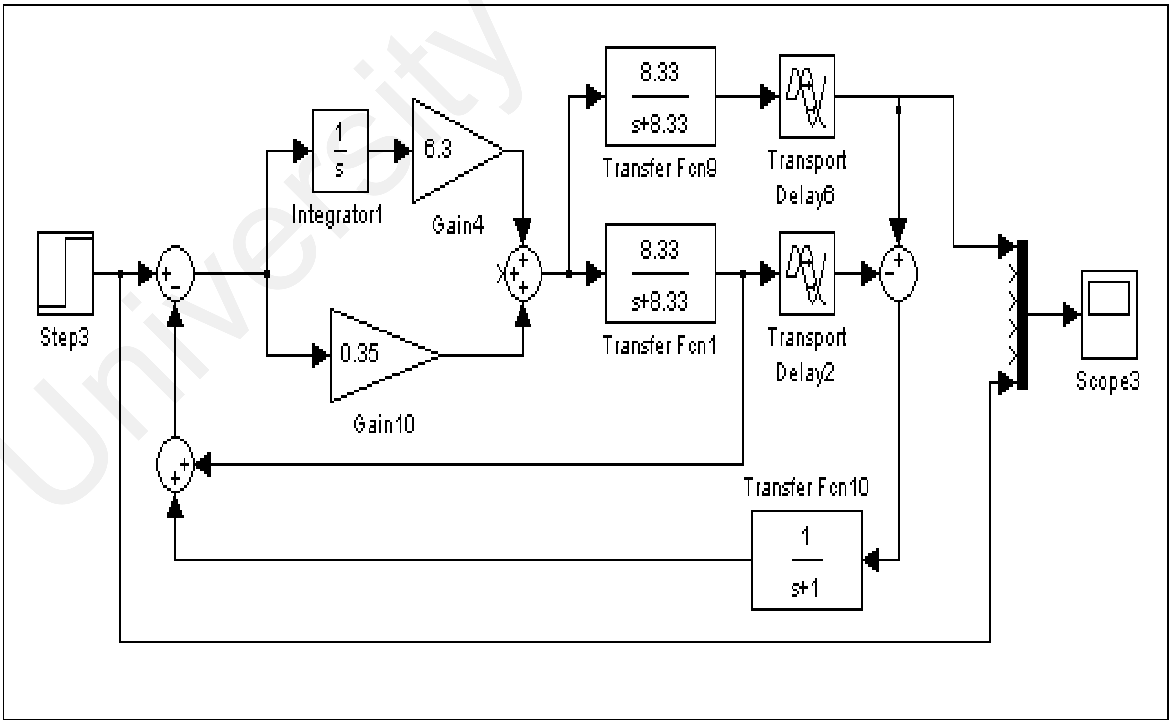

Figure 4.8: The block diagram of the developed PI controller enhanced by Smith Pridictor

The obtained graph is shown in figure 4.8 which clarify the settling time and rising time

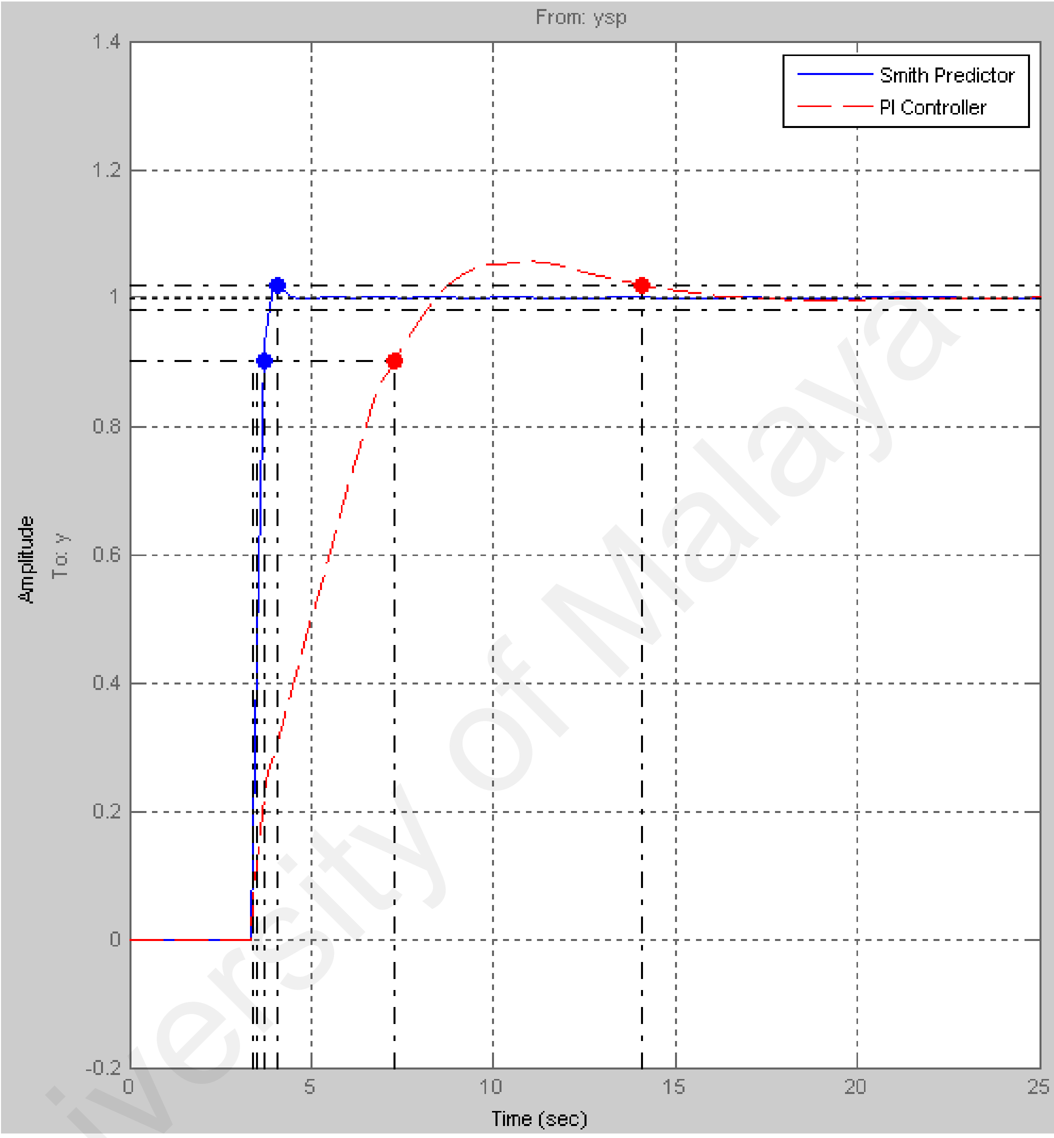

Figure 4.9: graph plot show the difference between the response of the system with PI controller only and the enhanced by Smith predictor

from the above graph Table (4.9) shows the difference between PI controller and Smith predictor

Table 4.9: shows the difference between PI controller and Smith

	Developed PI controller	**PI enhanced by Smith Predictor**
Rise time	7.16	3.68
Settling time	14.1	4.06
Notes	Slow rise and settling time	Quick rise and settling time

4.5 Analysis and Discussions of PID Controller and Smith predictor

Figure 4.10 shows the block diagram of the developed PID controller enhanced by Smith Predictor and the PID values here have been optimized to fit the requirements of the new configuration .The low pass filter is added to magnify the error and enhance the prediction process so the new PID values which obtained to meet the requirements of the new configuration are as mentioned in table (4.10)

Table 4.10: PID values for the PID controller enhanced by Smith Pridictor.

Items	**Value**
Proportional band Kp	6.2
Integral band Ki	0.8
Derivative band Kd	0.18

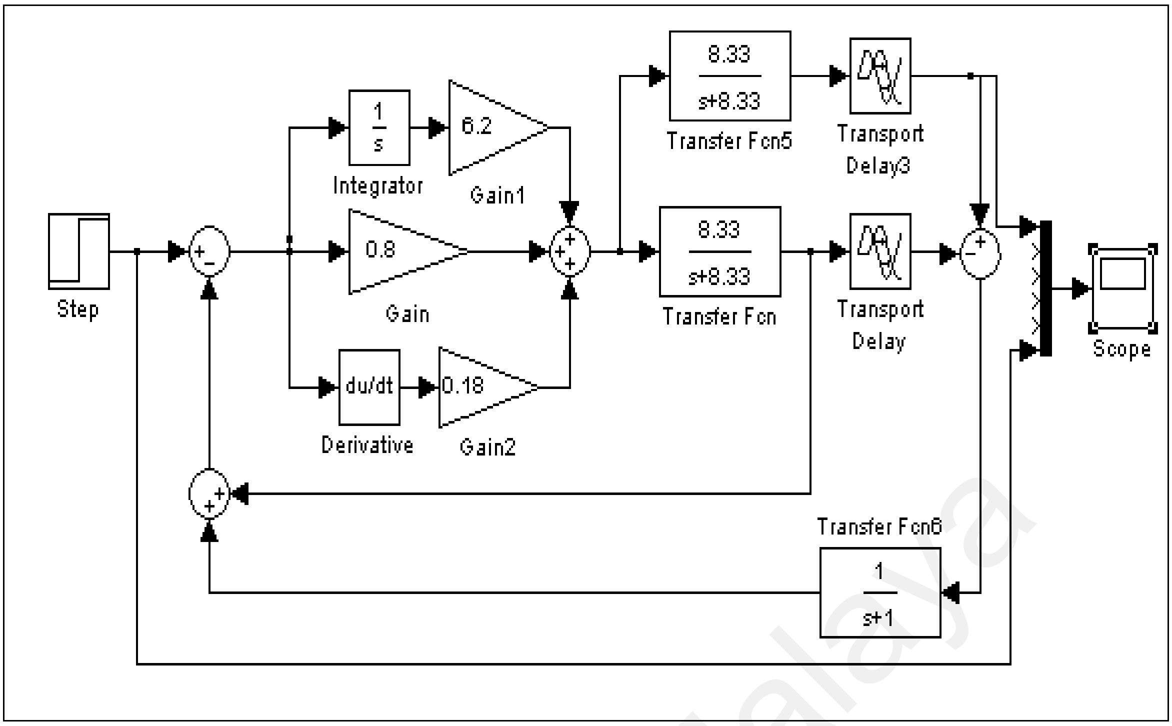

Figure 4.10: The block diagram of the developed PID controller enhanced by Smith Predictor

The obtained graph is shown in figure 4.11 which clarify the settling time and rising time

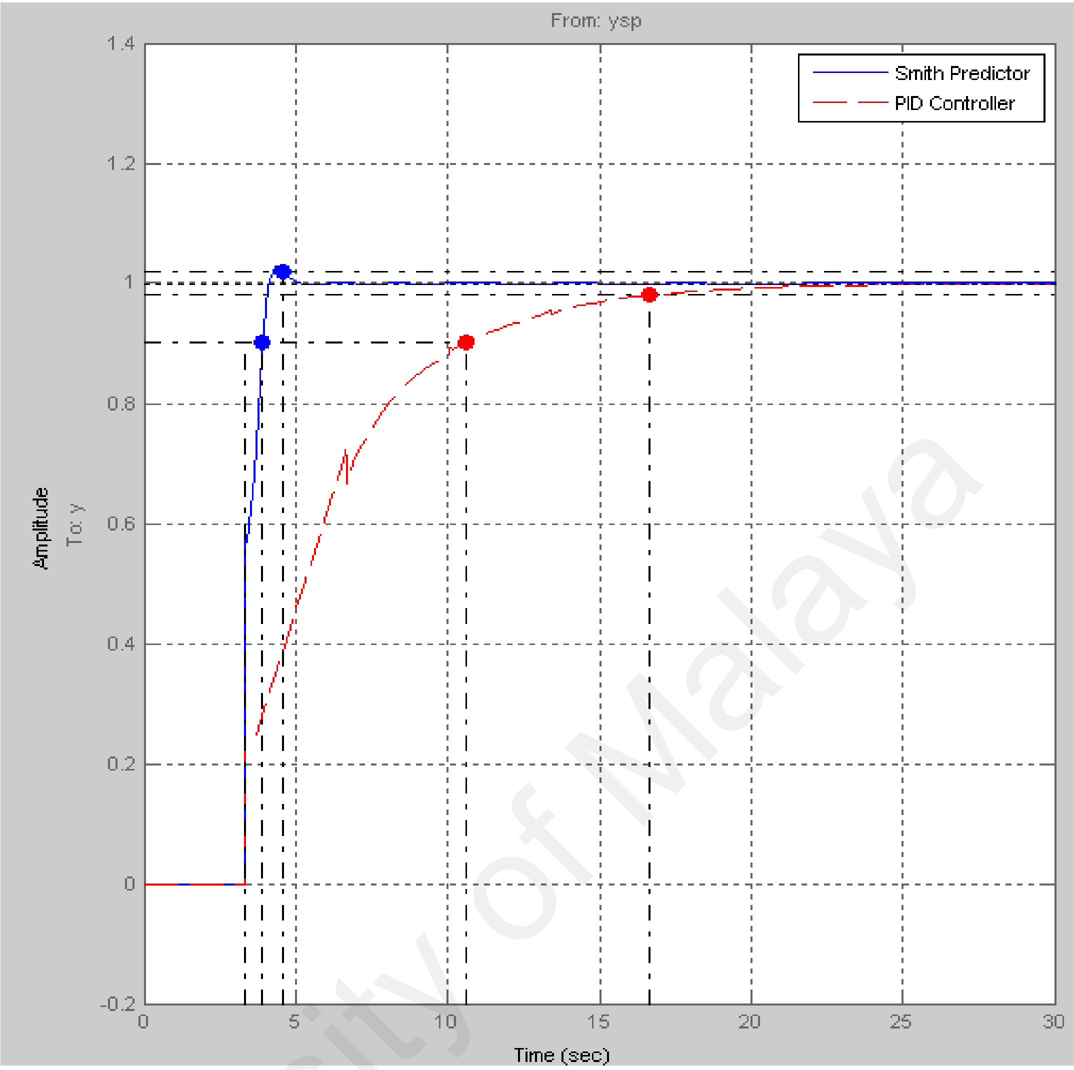

Figure 4.11: graph plot shows the difference between the response of the system with PID controller only and the enhanced by Smith predictor

from the above graph Table (4.11) shows the difference between PID controller and Smith predictor

Table 4.11: shows the difference between PID controller and Smith

	Developed PID controller	PID enhanced by Smith Predictor
Rise time	10.59	3.9
Settling time	16.7	4.58
Notes	Slow rise and settling time	Quick rise and settling time

4.6 Discussions

The comparison of simulated developed PI/PID controller and PI/PID controller enhanced by Smith predictor is shown in Figure 4.12 based on the summery of the comparison is in table (4.12)

Table 4.12: summery of comparison for simulation of developed PI/PID controller and PI/PID controller enhanced by Smith predictor

	Developed PI controller	PI enhanced by Smith Predictor	Developed PID controller	PID enhanced by Smith Predictor
Rise time (s)	7.16	3.68	10.59	3.9
Settling g time(s)	14.1	4.06	16.7	4.58

From the plotted graph, when the PI/PID controller enhanced by smith predictor is used, the time response is improved. Less time response PI/PID controller enhanced by smith predictor is where the raise time got up to 50% improvement and the settling time achieved more than 60% improvement and equation.

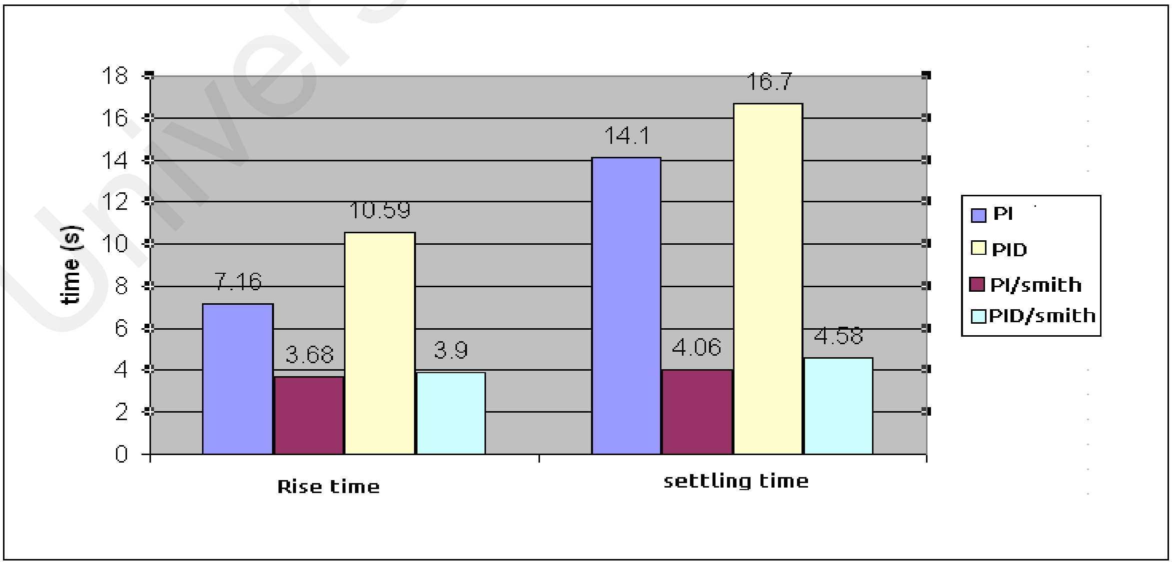

Figure 4.12: The comparison of simulated developed PI/PID controller and PI/PID controller enhanced by Smith predictor

4.7 Comparing error value of PI controller vs PI enhanced by Smith predictor

It's obviously shown in Figure 4.13 error signal can be measured by taking the reading from E(S)

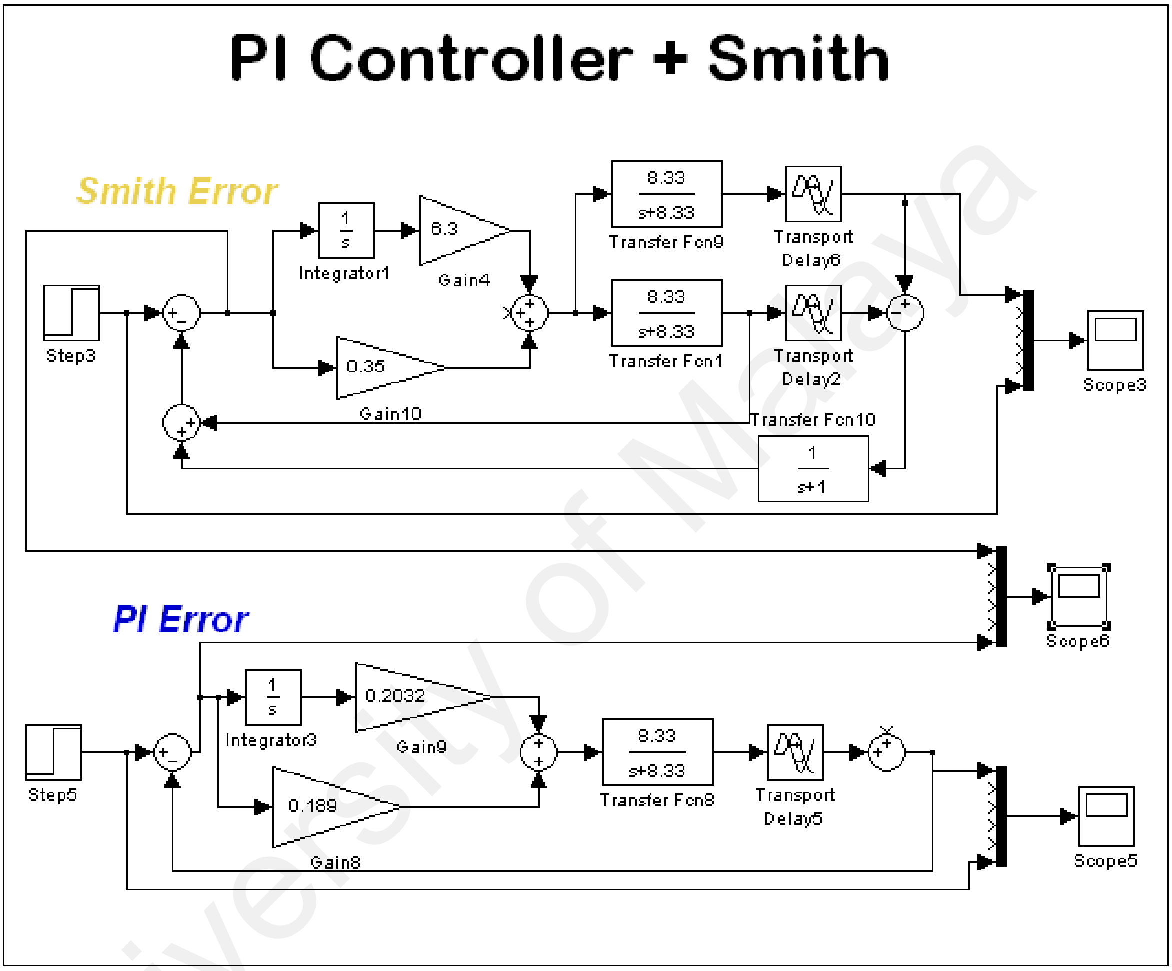

Figure 4.13: Taking the Error reading of PI controller and PI controller enhanced by Smith Predictor

The obtained values of error measurements are shown figure 4.14 proves that the PI controller enhanced by Smith predictor needs very short time 2 s only to eliminate the error while PI controller spends around 18 s until error has been eliminated which means that the reliability of the PI controller enhanced by Smith predictor is more than the normal PI controller

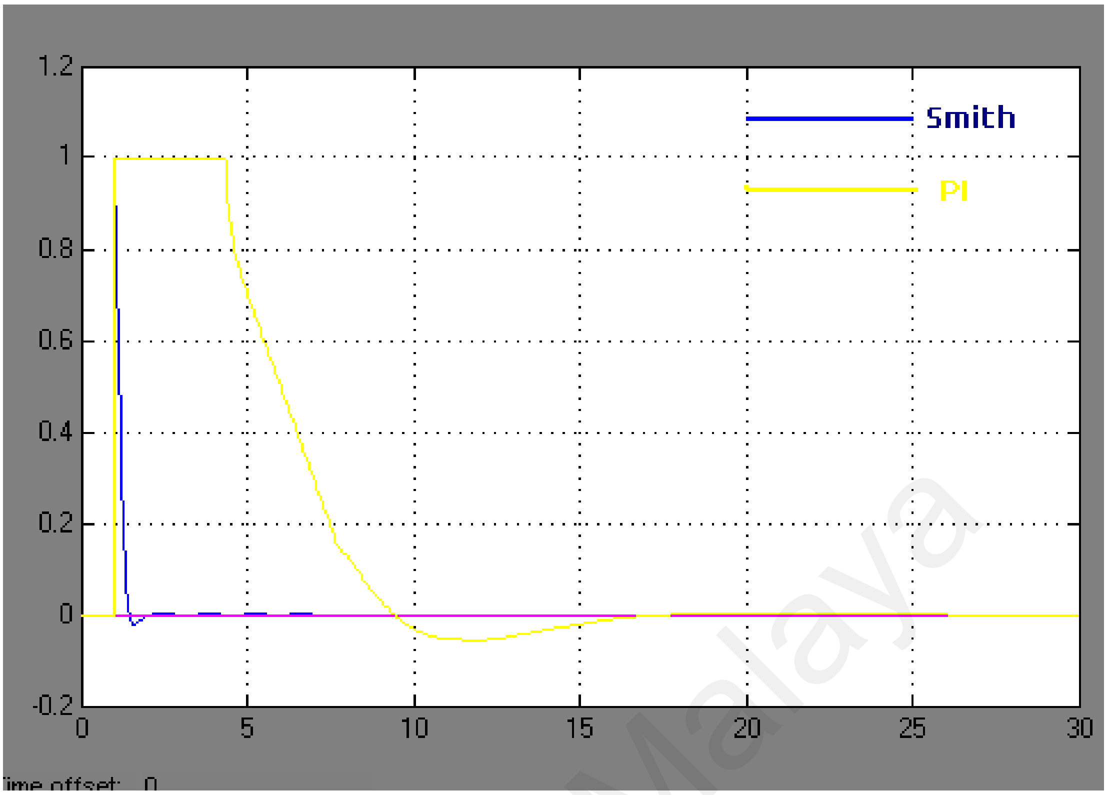

Figure 4.14: Error values of PI controller which needs 18 s to be eliminated vs PI controller enhanced by Smith Predictor which have been eliminated with in 2 s

4.8 Comparing error value of PID controller vs PID enhanced by Smith predictor

It's clearly as shown in Figure 4.15 error signal can be taken its measurements from E(S)

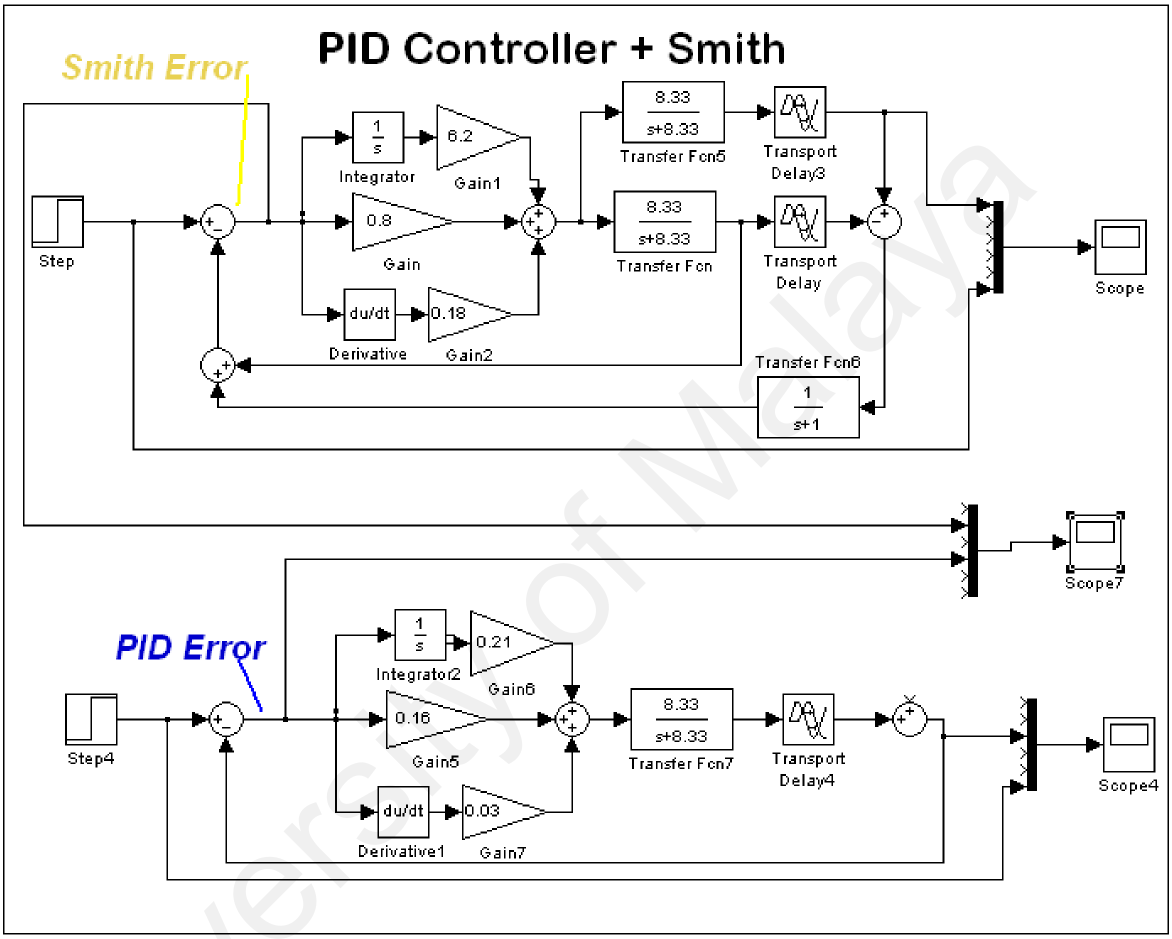

Figure 4.15: Taking the Error reading of PID controller and PID controller enhanced by Smith Predictor

The obtained values of error measurements are plotted in figure 4.16 demonstrates that the PID controller enhanced by Smith predictor requires very short time 2.5 s only to eliminate the error while PID controller spends around 18 s until error has been eliminated which means that the reliability of the PID controller enhanced by Smith predictor is more than the normal PID controller

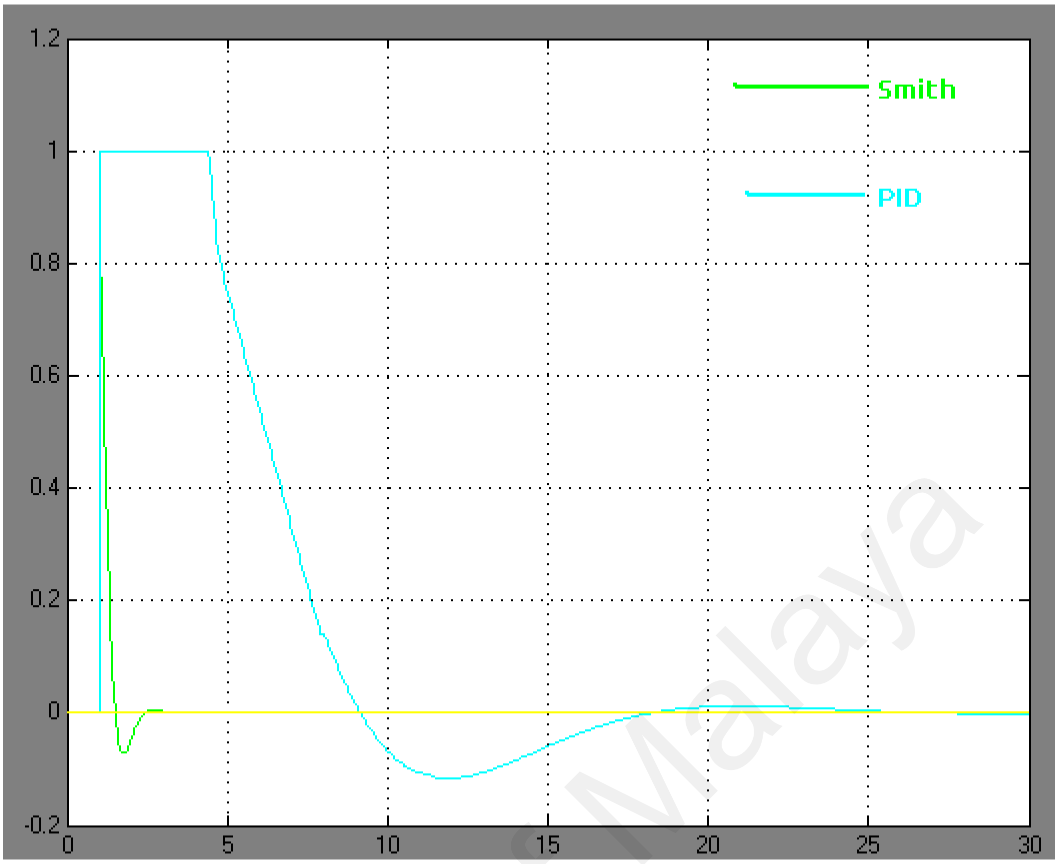

Figure 4.16: Error values of PID controller which needs 18 s to be eliminated vs PID controller enhanced by Smith Predictor which have been eliminated with in 2.5 s

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

A PI/PID controller developed and enhanced by using smith predictor method has been designed and simulated by using MATLAB/Simulink software. The proposed enhanced Anti surge controllers solved the problem of the dead time by obtaining time response faster than the normal PI/PID anti surge controllers.

The optimum time response has been obtained and the MATLB /Simulink simulation showed that the values of the enhanced PI/PID controllers have achieved a less time response by reducing the rise time, settling time and overshoot

5.2 Recommendation

Although this research project has been developed PI/PID anti surge control enhanced by smith predictor model only, other types of control can be used with this developed controller in industrial filed .like variable speed drive of reverse inlet valves , motors of compressors to form multiple controls compressors like sequencing valves in recycling line or load of the motors

All of these improvement and more can be enrich area of study in the future Addition enhancement to the simulation would be available with the new libraries of MATLAB/Simulink for the fluid system.

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