ISTANBUL UNIVERSITY-CERRAHPASA
INSTITUTE OF GRADUATE STUDIES

Ph.D. THESIS

MODELLING AND CONTROL FOR LEVEL SEPARATOR WITH UNSTABLE FLOW USING INTELLIGENT CONTROLLER

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March, 2023

THESIS ACCEPTANCE AND APPROVAL

This thesis titled Modelling And Control For Level Separator With Unstable Flow Using Intelligent Controller , prepared by Adel ELBOUSAIFI under the supervision of **Prof. Dr.** Abdul Rahman HUSSIAN, was accepted as a **Ph.D. Thesis** after being **consensus** approved by our jury as a result of the exam held on **13/03/2023**.

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Adel ELBOUSAIFI

(Signature)

I thank Allah for allowing me the health and fortitude to allow this effort to reach the light. I dedicate this thesis to my beloved family. I am also really appreciative of my supervisor and the monitoring committee for their comments and advice. There are not enough words to express my gratitude to everyone who supported me to complete my thesis … …

FUNDING

THESIS TITLE

No financial support was received from any institution for this thesis.

ACKNOWLEDGEMENT

I would like to thank my supervisors Prof. Abdul Rahman HUSSIAN, Prof. Sedat BALLIKAYA, Prof. Naim AJLOUNI and Dr. Fadi for all their help and advice on my Ph.D. I would also like to thank my father who would not have otherwise been possible. I also thank everyone who taught me, and I do not forget to thank my wife, who was the best helper for me, and my children who endured alienation with me. I also appreciate all the support I received from the rest of my family and everyone who helped me one day. Finally, I would like to thank my country, Libya, for the scholarship that allowed me to do this dissertation.

March, 2023 Adel ELBOUSAIFI

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols	**Description**
h_w	: High water level
β	: Function of h
F_o	: Oil Flow
$h_{w_{sp}}$	: Set Point Of High Water
V_{wier}	: Volume After Wier

Abbreviations	**Description**
ANFIS	: Adaptive Neuro-Fuzzy Inference System
PID	: Proportional - Integral - Derivative
FLC	: Fuzzy Logic Control
ANN	: Artificial Neural Networks
MIMO	: multiple input, multiple output

GENİŞLETİLMİŞ ÖZET

DOKTORA TEZİ

AKILLI DENETLEYİCİ KULLANARAK KARARSIZ AKIŞLI SEVİYE AYIRICI İÇİN MODELLEME VE KONTROL

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Ham petrol ve doğal gaz üretim tesisleri için üç fazlı ayırıcı kontrol sistemleri bu tezin ana odak noktasıdır. Özellikle ayırıcılara giren sıvı miktarı kadar basınçta da büyük dalgalanmalara maruz kalan üretim tesileri konu edinilmiştir. Dalgalanma, bu sistemleri ve ayırıcıları besleyen kuyulardaki ani basınç değişimlerinin sonucudur. Bu nedenle, denetleyici sistem kararlılığını koruyamaz hale gelmektedir. Bu tezin diğer amacı, sistemin özelliklerine dayalı olarak şu anda yürürlükte olanlardan daha akıllı denetleyici ayarlamasını mümkün kılmaktır. Amaç, sistemi çalışır halde tutmak ve sonuçta düzgün çalışmasını sağlamaktır.

Sistemin matematiksel modeli sistemin tüm parametrelerini içermektedir. Sistemin yapısını doğrulamak ve geliştirmek amacıyla çoklu giriş, çoklu çıkış sistemindeki tüm unsurlar göz önüne alınmış ve gerçek pratik sistemin bire bir simülasyonu oluşturulmuştur. MATLAB ve SIMULINK kullanılarak sanal bir sistem uygulaması geliştirilmiş ve simülasyon sonuçları elde edilmiştir.

PID (Orantılı - İntegral - Türev) denetleyiciler günümüzde sistemlerin kontrolünde hala başarılı bir şekilde kullanılsa da, bazı durumlarda yüksek dalgalanmalar karşısında sistem kararlılığını

korumakta zorlanmaktadırlar. Bu tezde tasarlanan PID denetleyici, önerilen çalışma ile karşılaştırma için bir temel sağlamayı amaçlamaktadır.
Tezin konusu bu sistem, doğrusal olmayan bir sistemden ayar noktasının yakınında doğrusal bir sisteme dönüştürülmelidir. Doğrusallaştırma olarak bilinen bu teknik, PID denetleyicinin doğrusal olmayan bir sistemde normal şekilde çalışmasına izin verir.
Akıllı denetleyicilerin doğrusal ve doğrusal olmayan sistemlerde iyi sonuçlar vermktedir. Akıllı denetleyiciler fonksiyonlarını en etkin şekilde lineer sistemlerle gerçekleştirdikleri için önerilen bu yöntem lineerleştirmeden faydalanmaktadır. Yukarıda bahsedilen dönüşümün nedeni budur.

Bir PID denetleyiciyle karşılaştırıldığında, akıllı bir bulanık mantık denetleyicinin kullanılması, sistemin daha kararlı olmasına, toplam kararlılık durumuna daha çabuk ulaşmasına ve mümkün olan en düşük kararlı durum hatasına sahip olmasına yardımcı olur. Bulanık mantık denetleyicinin çok iyi bir performansa sahip olmasına rağmen, gürültü seviyesinde bir artış olduğunda bulanık mantık denetleyiciden gelen sinyal oldukça değişkenlik göstermektedir.
Bir ANFIS (Uyarlanabilir Nöro-Bulanık Çıkarım Sistemi) denetleyicisi, sistemi stabilize edememe ve kontrol sinyalindeki dalgalanma gibi daha önceki denetleyicilerin karşılaştığı tüm sorunları çözebilmektedir. Bunun nedeni, denetleyiciyi başarılı kılan çok sayıda özelliğe sahip olmasıdır.
Ayırıcı sistemlerindeki sorunlar, akıllı denetleyiciler kullanılarak sistemlerin daha az sorunla ve daha kısa durma süreleriyle uygun koşullarda çalıştırılması sağlanabilir. Ayrıca önerilen akıllı denetleyiciler benzer sistemlerde kullanılabilir.

Mart 2023 , .119. sayfa.
Anahtar kelimeler: yerçekimi ayırıcı, ANFIS, bulanık mantık

ABSTRACT

Ph.D. THESIS

MODELLING AND CONTROL FOR LEVEL SEPARATOR WITH UNSTABLE FLOW USING INTELLIGENT CONTROLLER

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The three-phase separator control systems for crude oil and natural gas production plants are the primary focus of this thesis. Especially those that are subject to a large fluctuation in pressure as well as the amount of fluid entering the separators. The fluctuation is the result of sudden pressure changes in the wells that feed those systems and separators. Because of this the controller fails to keep system stability. The other objective of this thesis is to implement a tuning approach for more intelligent controls than those currently in place based on the system's characteristics. The aim is to keep the system from stopping and hence maintain its proper operation.

The entire system’s mathematical model incorporates all of the processing parameters. It deals with all of the elements in a multiple input, multiple output system for the purpose of verifying and developing the structure of the system, and it is one-to-one simulation of the actual practical system. MATLAB and SIMULINK are used to implement a virtual system in order to obtain simulation results.

Even though PID (Proportional - Integral - Derivative) controllers are still successfully used for systems today they in some cases suffer from maintaining system stability in the face of high fluctuations. The PID controller designed in this thesis is aimed at providing a basis for comparison with the work proposed.

Since this system is a non-linear one it must be transformed from a non-linear system into a linear system in the proximity of the set point. This technique, which is known to as linearization, allows the PID controller to operate normally on a non-linear system.

Intelligent controllers can work well with both linear and non-linear systems. This proposed method makes use of linearization since intelligent controllers perform their functions most effectively with linear systems. That is the reason of the afore mentioned transformation.

When compared to a PID controller, the utilization of an intelligent fuzzy logic controller helps the system to be more stable, achieve the state of total stability more quickly, and have the lowest steady-state error possible. Despite the fact that the fuzzy logic controller has excellent performance, the signal from the fuzzy logic controller is highly volatile when there is an increase in the noise level.

An ANFIS (Adaptive Neuro-Fuzzy Inference System) controller is able to solve all of the issues that were encountered by earlier controllers, such as the inability to stabilize the system and fluctuation in the control signal. This is due to the fact that it has a multitude of characteristics, all of which combine to make it extremely useful.

Problems in separator systems can be solved by employing intelligent controllers and operating the systems in favorable conditions, which include fewer problems and shorter periods of time during which they are exposed to shutdowns. In addition, intelligent controllers proposed could be used in systems that are similar.

March 2023, .119. pages.

Keywords: gravity separator, ANFIS, fuzzy logic

1. INTRODUCTION

1.1. OVERVIEW

With the development of life, people have become accustomed to consuming large amounts of energy, and this has made companies search for energy sources, especially sources of carbohydrates, oil, and gas. A simplified idea can be taken on oil and gas, how it is extracted and how it is formed. (International Energy Agency 2021) Which helps to understand the objective of this thesis.

Oil, also known as petroleum, is a naturally occurring liquid that can be discovered below the surface of the earth. This natural liquid has the potential to be refined and turned into a fuel source. It is known as a fossil fuel because it was created by the decomposition of organic materials over the course of millions of years while being subjected to high temperatures and pressures. (Gudde 2018).

It can be put into combustion to power equipment, automobiles, or heating systems (Mohaghegh 2018). In addition to this, it is believed to be a non-renewable source of energy because its formation required millions of years, and once it has been mined and used up, there is no way to produce more of it.

1.1.1. Brief On the Composition of Crude Oil

It is believed that algae and plants that once flourished in shallow oceans are the progenitors of oil. This theory dates back millions of years (Robertson 2011). When these animals eventually died and sunk to the ocean floor, the organic debris they left behind mingled with other sediments and was eventually buried beneath layers of sediment and other dead plants.

The organic matter started to change into kerogen, a waxy substance, as time passed, an increase in pressure and temperature occurred, and nearly no oxygen was present in the environment (Hartmann 2011).

A process known as catagenesis is responsible for the transformation of kerogen into hydrocarbons. This transformation takes place as a result of an increase in pressure, temperature, and the passage of time.

The greater the depth of the wells, the higher the temperature and the pressure. The gas associated with oil in this situation is higher pressurized (Matar 2010). Greater gas pressure fluctuations result from this.

Because of this oscillation, classic controllers have a difficult time maintaining this state under their control. This is the issue that this thesis attempts to address. In an effort to use more advanced controllers, Intelligent Control will be implemented.

Inside this section, designers offer a straightforward three-phase separators model for liquids levels and pressure management and assess the separating effectiveness for the continuous phases of wastewater and crude oil, accordingly.

three principal mathematical formulations that describe the levels of the total liquids and wastewater in addition to the natural gas pressure subjected to outflow and inflow behaviors are included in the model. (Christoph 2017).

Complicated and difficult, the dynamics of oil-producing plants. To address the objectives of designing, controlling, and optimizing such systems, a computational mathematics analysis using dynamic equations was conducted.

The three-phase separator, where the dynamic of each phase is analyzed, is the main subject. Good plant analysis skills and system expertise are needed for this approach. (Taylor 2007).

Complicated mathematical and numerical techniques have been used to model the fluid mechanics of the separator's component parts. models that explain how liquids in petroleum phase separation agglomerate and settle.

These models account for the dimensions of the separator, flow velocity, physical characteristics of the fluid, liquid quality, and droplet size distribution. These models' production is the standard of the petroleum they produce. (Hafskjold 1997).

The researchers have completed interesting research (Kumar & Nagpal, 2017) on a system comparable to the one on which this research will be done. It is the tank's liquid level monitoring system. In instances when the researcher compared classic control to intelligent control, it was used in PID control in the first instance and fuzzy logic control in the second.

Process industries control uses the PID algorithm due to its simplicity and ease of deployment. As it is difficult to determine an appropriate gain, a PID controller uses mathematical modeling.

A classic P controller can only erase the actual error. The PI controller works well for low-order processes when sensitivity is not important, but not for higher-order systems. Human thinking makes a fuzzy logic control system flexible and understandable. Comparing and validating the simulation result in MATLAB Simulink reveals that a fuzzy logic controller performed best than PID controllers. (Kumar & Nagpal, 2017)

controller of MIMO nonlinear systems, the self-tuning PID controller strategy was suggested. Control was provided by a vector of addresses of various aspects generated using the Gauss-Newton technique until the PID parameter attained its ideal value. As a result, the control goal was achieved after PID tuning, and the action was then carried out with the pid Based controller. Finally, input and output data pairs gathered from the system were used to create the ANN model. (Bıdıklı 2018).

The most effective PID controller parameters were found using Mathematical and Simulink. They used the Cohen-Coon, Ziegler-Nichols, and Yuwana-Seborg tuning procedures to determine the control calculated results for the ISE and IAE. MATML/Simulink-designed closed-loop Pid with water level system block diagram was used to calculate the numerical values of the responses for the runs. MATLAB/Simulink-designed closed-loop Controllers with a water-level system block diagram was used to calculate the numeric value of the responses for the runs. (Aldemir 2020).

They provide three-phase separator algorithms to perform streamlined particle equilibrium calculations. The liquid, wastewater, and natural gas pressure values are assumed to be the dynamic states, whilst the locations and number of droplets are thought to represent the algebraic states.

This study's objective is to examine the impact of various water content levels on the general effectiveness of water separation from oil. With the addition of ten static particle classes and the division of the separator size into smaller volumes, they have created an expanded model. belonging to the three-phase separator.

1.1.2. An Overview of the Problem

The problem being addressed can be separated into three parts:

The first is due to pressure, because of the increased pressure and greater pressure fluctuation caused by the existence of crude oil wells at great depths, it is now more difficult for industries to keep their separation systems stable. As a result, research on solutions to this issue has begun.

The formation of the new issue, the fluctuation in fluid flow, crude oil, and related wastewater, was also a result of the preceding issue.

Another issue is that the liquid level in the separators becomes unstable due to the gas bubbles, which is a separate issue.

1.1.3. The Objective of the Study

This study is built around a number of objectives, the objectives are summarized as follows:

- The reduction of the impact of pressure fluctuations.
- To maintain system stability without reducing production.
- Investigating the use of intelligent control.
- Carrying suitable Analysis on the characteristics of the controllers being presented in this study.
- Carrying a broad comparison of those controls in different conditions simulates those in the oil industry.
- Compare the results of the intelligent control and the results of classic control.

1.1.4. Methodology of the Research

First, a method for mathematical representation's proportions and the separator system's operation are carefully investigated.

We perform a mathematical study of the system to ensure that there are no flaws in the structural design of the system. Following the development of the mathematical model of the system, our next step is to search for the most effective simulation techniques.

When Simulink and developing the system on an internal, we recommend utilizing MATLAB.

In addition to using classical controls, we are building some intelligent controllers.

Suggested controllers to use When discussing classic control, PID control immediately comes to mind. Both are going to be utilized in the P, PI, PD, and PID control techniques.

Some intelligent controllers will be proposed based on their operation method to suit the system we are developing.

- Fuzzy Logic Control FLC
- Artificial Neural Networks ANN

- Adaptive Neuro-Fuzzy Inference System ANFIS

1.2. MODELING AND DESIGN OF THREE-PHASE SEPARATOR

The modeling and design of simple three-phase separators are outlined in this section. It includes a collection of quantitative and qualitative relationships. For the time being it assumes perfect gas behavior and isothermal conditions.

They do not consider any particular aspects of geometry. In the future, this will be utilized in the process of analyzing the HYSYS model. The schematic diagram of the separator's three-phase operation can be found in Figure 1.1. (Paul I. Barton 1997)

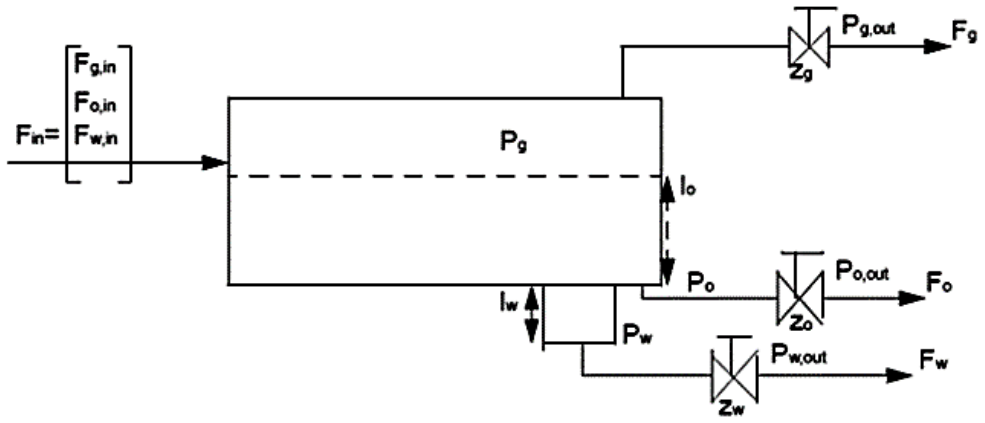

Figure 1.1: Three-phase schematic diagram of the separator

The system has one seal, which is the input through which crude oil, wastewater, and natural gas accumulate. This is visible in the drawing that was recently presented, so we know that this is the case.

The three-phase separators are shown in their condensed version in this schematic design. We can by understanding how to calculate some physical fluid variables. but in a very basic manner.

Before delving into the subject matter that will be the focus of our research, it is essential to have a fundamental understanding of the laws that govern fluid mechanics.

This is because having this knowledge will make it much simpler for us to comprehend a great deal of the material that is connected to the mathematical analysis of the system as well as the design of the system itself.

These laws are considered to be the fundamental laws. In order to take into consideration variables like flow pressure and other physical changes that we must deal with throughout the course of this research

Below is an explanation of the variables:

Fg. represents gas supply flow rate; Fo,in rate of oil input flow; fw,in: rate of wastewater supply; Fg: release of gas in flow; Fo: Outflow of oil; Pg: gas pressure; Fw: wastewater outflow; lo: oil level; lw: wastewater level; Po: pressure of oil; Pw: pressure of wastewater.

There are mass equations for the tree-phase separator:

The gas mass balance in the separator consists of:

$$F_{g(in)} = \frac{dMg}{dt} \tag{1.1}$$

The mass of crude oil inside the separators can be calculated.

$$F_{o(in)} = \frac{dM_o}{dt} \tag{1.2}$$

The mass of wastewater inside the separators can be calculated.

$$F_{w(in)} = \frac{dM_w}{dt} \tag{1.3}$$

1.3. THE FLOW RATE

1.3.1. Gas Flow Rate

The use of the law of flow makes it feasible to calculate amounts. Due to the various flow velocities and degrees of friction, the fluid will be referred to as "the fluid" regardless of whether it is a gas or liquid**.**

The flow of gases is determined by a number of factors, one of which is the pressure of the primary, which refers to the pressure within the tank or the pressure that exists just before the drain valve. Another component is the pressure that exists at the outlet. In addition to that, it is contingent upon the diameter of the drain valve as well as the coefficient of the valve. This is because every type of drain valve is distinct from the others. (Paul I. Barton 1997)

Calculating the flow can be done with the help of the following equation:

$$Fg = K_g\, Z_g \sqrt{p_{g(in)}{}^2 - P_{g(out)}^2} \tag{1.4}$$

kg is constant value for gas valve coefficient. Z_g valve diameter size.

This is the universal law that is applied when determining flow rates. It is clear that this is dependent not only on the pressure, but also on the diameter of the valve and the coefficient of the valve itself.

1.3.2. Crude Oil Flow Rate

We can determine the flow rate of oil using the same method that we used to calculate the flow rate of gas.

The crude oil flow rate is explained in the following equation:

$$F_o = K_o\, Z_o \sqrt{P_o - P_{o(out)}} \tag{1.5}$$

The oil pressure (Po) depends on the gas pressure (Pg) and oil hold-up (Mo). ko is the oil valve constant. We make notice of the fact that the law of flow in liquids is essentially identical to the law of flow in gases, with the exception of the fact that the square root of pressure is not taken into consideration.

$$P_o = P_g + F_w(M_o) \tag{1.6}$$

The oil pressure goes raised in proportion to the increase in the oil hold-up. This is in preparation for the possibility that the gas pressure is low.

Due to the pressure P1 being greater than the liquid pressure, which results in P2=P1+gh = P1, the output flow is not considerably affected by the liquid level.

1.3.3. Water Flow Rate

The approach that we utilized in order to calculate the flow rate of gas may also be utilized in order to measure the flow rate of water.

The following equation provides an explanation for the actual flow rate of wastewater:

$$F_w = K_w\, Z_w \sqrt{P_w - P_{w(out)}} \tag{1.7}$$

The wastewater pressure (P_w) depends on the gas pressure (P_g), oil hold-up (M_g) and water holdup (M_w). kw is the water valve constant.

The wastewater pressure, denoted by Pw, is determined by the natural gas pressure, denoted by (P_g) as well as the crude oil holdup, denoted by (M_g) and the water holdup (M_w).

The wastewater valve has a constant that is denoted by kw.

$$P_w = P_g + f_w(M_w, M_o) \tag{1.8}$$

1.3.4. Ideal Gas Low

The equation of state for a hypothetical ideal gas is referred to as the ideal gas law, which is often referred to as the universal gas equation. Despite certain shortcomings, it offers a trustworthy estimation of the behaviors of various gases in various circumstances. The first person to describe it as a combination of the empirical laws of Boyle, Avogadro, A and Gay Lussac was B. Paul É. Clapeyron in 1834. Clapeyron described it as combining these laws (Clapeyron, 1835). There are a great number of research publications that deal with this subject. When doing calculations in chemistry and physics, this law is absolutely necessary. When discussing the volumes and flows of liquids, as well as chemical reactions that take place in gases, we rely on this law. Additionally, when it comes to discussing chemical reactions that take place in gases, we employ this law. and because of this, it is referred to as the universal law of gases.

It is common practice to write the ideal gas law in an actual form, as follows:

$$P\,V \;=\; N\,R\,T \tag{1.9}$$

Where N is the amount of substance, P denotes the pressure, T denotes the temperature, and V denotes the volume; R denotes the ideal gas coefficient constant. It is also possible to identify it from the microscopic kinetic theory, which was discovered (seemingly separately) by (August K. 1856) and (Rudolf 1857).

In the chemical and physical computations of gases, this law is said to be the one that is utilized the most frequently. The dimensions of several gas variables are going to be calculated with its use in this thesis.

1.3.5. Compositional Formula

The three phasing elements that we take into account are natural gas, crude oil, and wastewater. It makes sense that both the amount of $X_{\text{crude oil}}$ in X_{water} and the amount of wastewater in crude oil are impacted by the relative (holdup times) (Moran 2010).

$$X_{water,oil} = f_{wol}(\tau_{oil}) = f_{wo}\left(\frac{N_o}{F_o}\right) \quad (1.10)$$

$$X_{oil,water} = f_{owl}(\tau_{water}) = f_{owl}\left(\frac{N_w}{F_w}\right) \quad (1.11)$$

$$x_{m,i,j} = \frac{M_{i.}\, e^{-\tau_{m,j}/\tau_{(ref,j)}}}{\sum_{k=1}^{3} Mk} \quad (1.12)$$

three phase separators are the beginning of a line of separation plant used in oil and gas manufacturing units to separate natural gas, crude oil, and wastewater in three or more phases. It provides nourishment to specialized processing units intended to designate each of those streams for exports.

The petroleum industry places a significant emphasis on separators despite the fact that these devices are among the industry's more uncomplicated systems.

The input flow separator in crude oil plants usually oscillating, and it is commonly distinguished with slugs of liquids and gases entering from of the wells. As we were discussing the components of crude oil before, we said that, as we mentioned earlier.

This fluid flow is known in the industry as slug flow, but the term is used widely (Shinskey, 1996; Skogestad, 2003).

When there is oscillation occurring within the system, it is difficult for controllers to take the proper action when the time passes.

In addition, in order to reduce the sizes of inshore plates, significantly more compact instrumentation is being used for the treatment of wastewater

and crude oil. This trend is expected to continue. Because of their decreased volume, they are particularly sensitive to oscillations (Nunes, 2004).

In order to manage the level and the pressure, proportional and integral PI controllers are utilized. Therefore, it would be beneficial to have algorithms that is capable of dampening the oscillatory feed of three phase separators.

The objective is to keep crude oil level, wastewater and natural gas pressure within acceptable parameters while keeping the controlled flow as consistent as is possibly practicable. (G. Nunes,2007).

The available research contains a great number of suggestions of this kind, such as nonlinear controller, cascaded controller, proportional controller, etc., all of which are given under a great number of various titles, such as surges controller, levels averaging controller, etc.

Nevertheless, from a practical standpoint, the majority of those implementations have a number of significant drawbacks: part of them need for additional measures (such as rate of flow), everyone else is difficult to adjust, and a few them permit an excessive amount of volume change (Cheug & Luyben, 1979).

1.4. PI AND PID CONTROL

1.4.1. PI Level Controller

The PI, PID, and PD controllers are regarded as some of the controllers that are utilized in the industry the most frequently, particularly in the oil business as well as other industries.

Take into consideration the mass distribution of the fluids contained in the separator. Given that there is a linear relation between both the maximum height h and the volumes, in which case the volume is equal to C D h, (Nunes, 2004).

the following formula can be used to calculate the volume of a separator vessel with the following dimensions:

$$V = Ah = CDh \tag{1.13}$$

The volume can be determined by applying this law, which is accomplished by multiplying the height by the width of the base.

It is possible to calculate the following equation that has a time variable:

$$A\frac{\acute{dh}(t)}{dt} = Q_{in}(t) - \acute{Q}_{out}(t) \tag{1.14}$$

when Qin represents the volumetric rate of flow of the input and Q_{out} represents the volumetric rate of flow of the output. The time component of the equation can be used to compute the volume by determining the quantity that is put into the tank and the amount that is taken out of

it. A straightforward formula for the actuator can be used to give an accurate description of the flow:

$$Q_{in}(t) = K_V u(t) = C_V\left(\sqrt{\Delta p}\right)u(t) \tag{1.15}$$

when u represents the controller signal, CV represents the mass flow coefficients, and Δ P represents the pressure difference caused by the valves. Take into consideration the fact that the behaviors of the valves are significantly faster in comparison to those of the different of the system's components. This indicates that the controller signal, denoted by the letter u, functions in a manner that is analogous to the open of the valves.

$$Q_{in}(t) = K_V u(t) = C_V\left(\frac{f(x)}{1.16}\sqrt{\frac{\Delta P}{\gamma}}\right)u(t) \tag{1.16}$$

when CV represents the stream coefficients, f (x) represents the valves characteristics, x represents the proportion of the valves that is open, ΔP represents the pressure difference that occurs within the valves, represents the relative densities, and u represents the controller signal. If the dynamics of the valves are considerably quicker while the deal times remains relatively constant, this indicates that the controller action, u, is equivalent to the open of the valves. The equation is as follows:

$$A\frac{\acute{d}h(t)}{dt} = Q_{ın}(t) - \acute{K}_V\acute{U}(t) \tag{1.17}$$

Following is the formula that can be used to get the Laplace Transform for the previous equation:

$$H(S) = \frac{1}{AS}(Q_{ın}(s) - \acute{K}_V\acute{U}(s)). \tag{1.18}$$

description and calculation are impacted both by the types of control valves as well as their sizes and speeds.

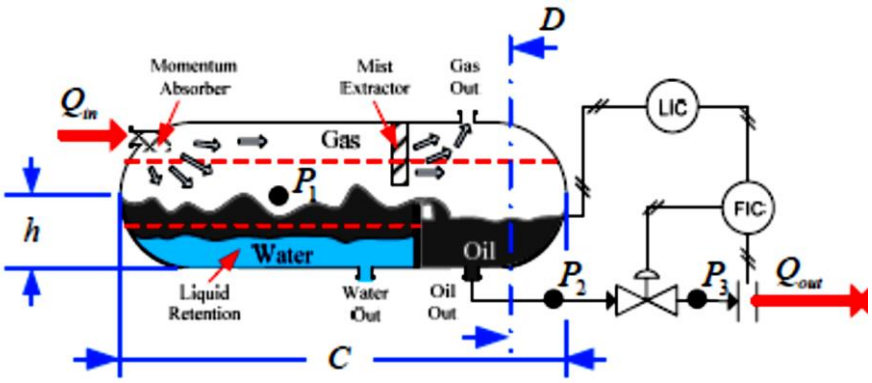

Figure 1.2: Three phase separator

The simplified diagram that was just presented demonstrates a few different separator concepts in addition to the instrumentation that is put on these separators. Level control is a typical application for PI controllers, and the transfer function can be written as (Åström, 1994).

$$U(S) = \overline{K_c}\left(1 + \frac{1}{s\overline{T_1}}\right)\left(HR(S) - H(s)\right) \tag{1.19}$$

when Kc T1 represent PI parameters and hr(s) is the reference point or set-point. The design blocks. and, respectively, a three-phase separator's PI control method are shown in Figures (1.3) and (1.4). (Skogestad, 2003.Wu 2001).

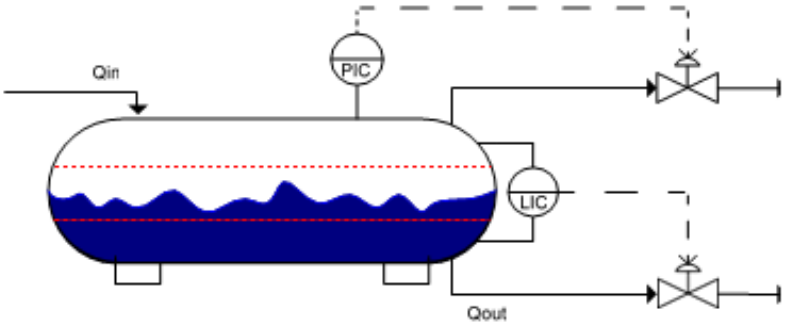

Figure 1.3: Diagram of three-phase separator

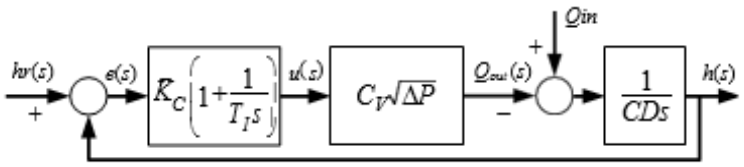

Figure 1.4: PI controller of a three-phase separator

1.4.2. Band Controllers Design and Development

The same starting control law, equation, can be used to create a simpler and more reliable controller (10). Consider the valve's equation $Q_{in}(t) = K_V u(t) = C_V\left(\sqrt{\Delta p}\right)u(t)$, which connects the valve's opening to the outflow. We obtain a control law that is independent of flow data by substituting it in equation (10)

$$Q_{out}(s) = \left(1 + \frac{1}{s\overline{T_1}}\right) Q_{out}(s) + \left(\frac{CD}{T}(1 + e^{Ts})h(s)\right) \tag{1.20}$$

1.4.3. Design For an Adaptive Band Controller

Every moment the level exceeds the band's boundaries, the band control is changed to a rapid PID. An adaptive idea is suggested in order to prevent employing the PID and also to increase the robustness of band approach. The gain (K) of the Band Controller, equation (1.21), which is the adaptive control term, is modified in accordance with some criteria that specify when the level is outside of bounds.

The following two notions are put into practice (Ljung, 1999):

$$U(s) = \left(\frac{1-e^{-Ts}}{Ts}\right) U(s) + Ke(s) \tag{1.21}$$

Dampening changes in regulated flow while maintaining the level of liquid within the three-phase separator within acceptable limits are the primary responsibilities of a level control on a three-phase separator.

When the level is outside the operating limitations, the adaptive band control algorithms do not implement a PID. In conclusion, with regard to these two possibilities, it has been shown that adaptive band controller algorithm can accomplish desirable behaviors.

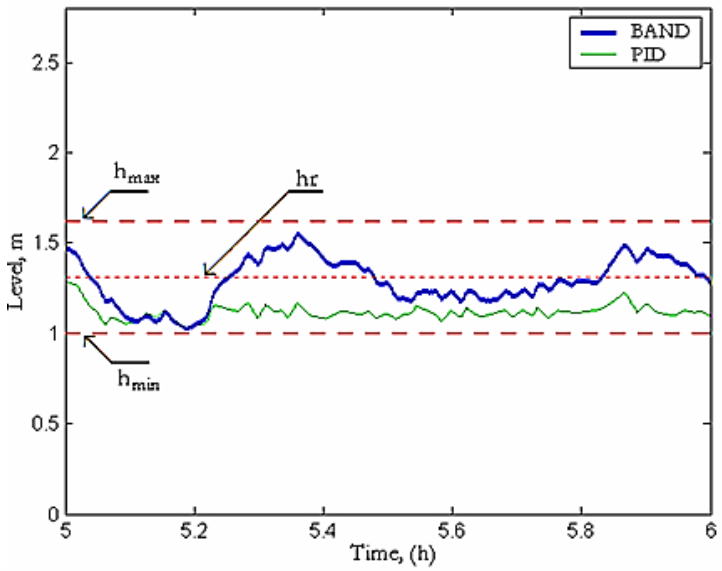

Figure 1.5: depicts the level response of band and PID controllers.

Result demonstrate how effective outflow filtration is. The levels are typically maintained within the band's parameters. Be aware that the band's maximum capacity (12.8 m3) corresponds to a wavelength between 1.5 and 1.1 meters. If another band had been available that matched the same volume, it may have been used instead.

The utilization of the mass balance in the creation of controllers that steady the output of accumulating vessel is something that has been investigated (Filho 2004). It has been demonstrated that one should refrain from making use of derivatives of the manipulated variable.

A creative and straightforward control algorithm that is centered on material equilibrium has been introduced. It has been demonstrated that in spite of its seeming simplicity, the performance it offers is superior than that of other algorithms with comparable features (Luyben 2000). An alternative form is demonstrated here for use in the PID's implementation.

The preceding approach, despite having a number of positive benefits, also has a few disadvantages. things can't be disregarded in any way. The fact that he did not obtain the right mathematical representation of this system using the approach that should have been used to do so is the method's most significant flaw.

It operates on the assumption that the system is a signal input signal output ISOS system and treats it accordingly. There are some inaccuracies in this statement. This system would need to be regarded as a MIMO system, which stands for multiple-input and multiple-output.

There are also some unsatisfactory results. It is not the same thing as complete stability. It's possible that this is because of a mistake in the modeling approach that was taken.

1.5. THREE-PHASE SEPARATOR USING QUADRATIC LINEARIZATION DESIGN AND ANALYSIS

Control systems that make use of the linearization of nonlinear systems have recently come into prominence and have gained widespread acceptance among experts in control systems.

The modeling approach of a three-phase separator exhibits nonlinear behavior in several respects. For the purpose of controlling the three-phase separator, numerous control strategies have been suggested.

Separators are the devices that are responsible for the phase separation of crude oil, wastewater, and natural gas from the oil that is produced in crude oil facilities. The surface output of petroleum companies is significantly aided by the utilization of three-phase separators (Mostafaiyan 2014).

A decrease in operational costs and an improvement in the total production efficiency can be achieved by controlling the three-phase separator in an efficient way possible.

Nonlinear properties of the separators model present a difficult challenge when it comes to the implementation of a control method. In the research that has been done, approximative linearization of the three phase separators has never been taken into account., they begin with a differential equation that describes three phase separator.

Next, they transform the variable such that it may be written in the form of a typical state equations. The divergence of the parameter value from the equilibrium point is taken into consideration since the separators are operated under predefined set - point. As a consequence of this, a state equation in control quadratic form is produced.

After going through the process of (Quadratic linearization), the controlled linear system becomes a linearized structure that has third- and greater nonlinear effects. The preliminary findings of an experiment that used quadratic linearization to a three-phase separator with four inputs are provided in (Janakiraman 2017).

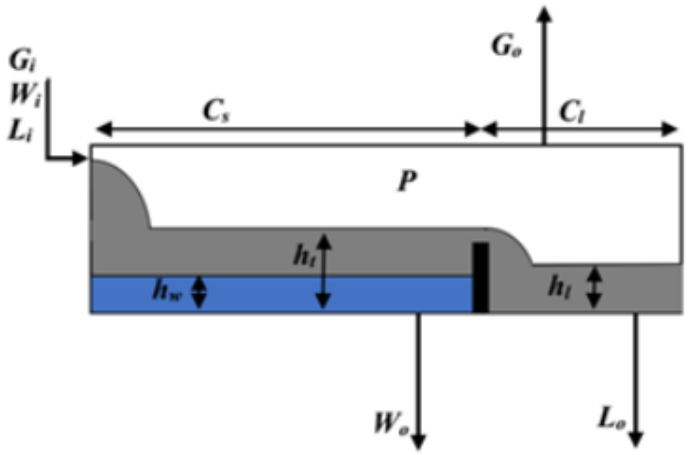

Figure 1.6: sketch diagram of separator

The separator that was used for this research may be seen in the figure that came before this one, along with the dimensions of the units that would be used later on in the process of calculating the system, its outputs and inputs, and how they are transformed into a linear system.

Within the focus of this research, they investigate the more difficult problems of linearization only using three inputs.

In the following discussion, designers will investigate at the nonlinear equation that describes the behavior of the three-phase separator. Taking into consideration the height of the wastewater level h_w in the separators beside vessel, the calculation could go as follows:

$$dh_w/dt = (Wi - Wo)/2C_s\sqrt{h_w(D - h_w)} \tag{1.22}$$

when Wi represents the rate of flow for wastewater entering the separator, Wo represents the rate of flow for wastewater leaving the separator, D represents the diameter of a separator chamber, and Cs represents the lengths of the separator vessel (Janakiraman 2017). When taking into account the combined height of the wastewater and crude oil, the following equation can be derived using the time coefficient, h_t:

$$dh_l/dt = (Li + Wi - Wo - L_V)/2C_s\sqrt{h_t(D - h_t)} \tag{1.23}$$

when Li represents the oil flow rates at the input and L_v represents the oil flow rates at the weir. Then, the height of oil hl after the weir is calculated using the equation:

$$dh_1/dt = (L_V - L_o)/2C_s\sqrt{h_1(D - h_1)} \tag{1.24}$$

when Lo represents the crude oil supply rates at the output and Cl represents the length of the crude oil vessel. Then, the natural gas pressure P at the separator vessel is described as

$$dP/dt = P\,(Li + Wi + Gi - Lo - G_O)/(Vt - V_{CS} - V_{C1}) \tag{1.25}$$

when *Gi* represents the rate of natural gas flow at the input, G_o represents the rate of natural gas flow at the output, *Vt* represents the capacity of the vessels, V_{cs} represents the liquids volumes in the separator, and V_{cl} represents the liquids volumes in the crude oil chamber (Janakiraman 2017).

The following variables can be used to determine the rise in the level of wastewater and crude oil on both sides, and they will also utilize this variable in the nonlinear equations. Additionally, this variable can be used to find the difference between the two levels.

We can use binomial expansion to calculate the solution by applying it to the expression that was generated by the equations. Let's say X_1, X_2, and X_3 are all set up so that:

$$h_w = (^{D}/_{(2 - X_1)}) \tag{1.26}$$

$$h_t = (^{D}/_{(2 - X_2)}) \tag{1.27}$$

$$h_1 = (^{D}/_{(2 - X_3)}) \tag{1.28}$$

They can be substituted onto the equation 1.25 using equations 1.26, 1.27 and 1.28.

$$d(D/(2 - X_1))/dt = \frac{d_1 k_1 - k_2 u_1 (2 - X_1)^{-(1/2)}}{\sqrt{((1 - X_1)(1/(2 - X_1)))}} \tag{1.29}$$

where the parameters of the procedure determine the values of the constants k1 and k2, respectively.

$$dX_1/dt = d_1 k_1\ (2 - X_1)^3\,(1 - X_1)^{-1/2} - k_2 u_1 (2 - X_1)^{5/2}(1 - X_1)^{-1/2} \tag{1.30}$$

Now extend (1.30) using a binomial series to reach the following result: Considering that x1 is sized suitably for the specified range of hw, then get:

$$dX_1/dt = d_1 k_1\ [8 - 8X_1 + 3X_1^2 + \tfrac{3}{16X_1^4} + \cdots] - u_1 k_2 [5.76 - 4.24X_1 + 1.24X_1^2\ + 0.22X_1^3\ - 1.33X_1^4\ + \cdots] \tag{1.31}$$

the dynamical variables, x, is obtained by appropriately transforming hw, h_t, and hl into x_1, x_2, and x_3 accordingly, and the equation for x is written as [x_1 x_2 x_3 x_4] t.

One can get by changing the values in (1.28) -(1.30) to those in (1.24) -(1.27) and then extending the terms that are produced through using binomial series.

$$\dot{x} = Ax + Bu + f^{(2)}(x) + g^{(1)}(x)u + O^{(3)}(x,u) \tag{1.32}$$

The A and B represent constants matrix of the proper dimension, as well as f(2)(x) where g(1)(x) represents vectors sectors that include elements of the 1th & 2ed order in x, correspondingly. O(3)(x, u) is the notation that matches to terms using x and u that are of order multiple or higher.

Following is a breakdown of the structure of the matrix A & B, as well as the vectors field f(2)(x) as well as g(1)(x).

$$A = \begin{bmatrix} -d_1 a_{11} & 0 & 0 & 0 \\ 0 & a_{22} + -d_1 a_{11} & 0 & 0 \\ 0 & 0 & a_{33} & 0 \\ 0 & 0 & 0 & a_{44}(d_1 + d_3) \end{bmatrix} \tag{1.33}$$

$$B = \begin{bmatrix} -b_{11} & 0 & 0 & 0 \\ b_{21} & b_{22} & 0 & 0 \\ 0 & 0 & b_{33} & 0 \\ 0 & 0 & 0 & b_{44} \end{bmatrix} \tag{1.34}$$

$$F_2^{(2)}(X) \begin{bmatrix} -X_1^2\, d_1 a_{12} \\ X_2^2(d_1 a_{24} + a_{25}) \\ (X_2^2 a_{31} + X_3 X_2 a_{34} + X_3^2\, a_{35}) \\ X_4(d_1 + d_2)(X_2 a_{41} + X_3 a_{42} \end{bmatrix} \tag{1.35}$$

$$g^{(1)}(X) = \begin{bmatrix} -X_1 b_{12} & 0 & 0 & 0 \\ X_1 b_{23} & X_2 b_{24} & 0 & 0 \\ 0 & 0 & X_3 b_{31} & 0 \\ X_4 b_{43} & X_4 b_{44} & X_4 b_{45} & X_4 b_{46} \end{bmatrix} \tag{1.36}$$

1.5.1. Quadratic Linearization

Linearization is a method for the research and control of nonlinear systems that is frequently utilized since it avoids the complexities that come along with nonlinearity. In this part, we demonstrate how quadratic linearization can be accomplished by removing all terms of lower order from the equation, leaving and anyone of 3rd & higher order. Take into consideration the following controller quadratic systems:

$$\dot{x} = Ax + Bu + f^{(2)}(x) + g^{(1)}(x)u + O(3)(x,u) \quad (1.37)$$

$$y = x + \phi(2)(x) \quad (1.38)$$

$$u = \big(I + \beta(1)(x)\big)v + \alpha(2)(x) \quad (1.39)$$

If A is an n-by-n matrices & B is an n-by-m matrices, when m-by-n, $f^{(2)}(x)$, & $g^{(1)}(x)$ represent vectors fields with orders of 2, 1, and 1, correspondingly. A modification to a coordinate frame and feedback are required in order to linearize the quadratic element of the systems.

The altered value and supply parameters are denoted by y and v respectively. By adding together equations (1.38), (.139), and (1.37) we may get the following formulae:

$$y\dot{y} = Ay + Bv + O(3)(y,v) \quad (1.40)$$

In this case, these quadratic elements are eliminated as long as the following requirements, which are referred to as pattern matching formulas, were achieved for those values of x (2), x (2), and x (1)

$$(X) - A\emptyset^{(2)}(X) + B\alpha^{(2)}(X) + \mathrm{f}^{(2)}(X) + \frac{\partial\emptyset^{(2)}(X)}{\partial X}AX = 0 \quad (1.41)$$

$$\left(B\beta^{(1)}(X) + g^{(1)}(X) + B\frac{\partial\emptyset^{(2)}(X)}{\partial X}\right)\upsilon = 0\forall v \quad (1.42)$$

The linear system of a quadratic receives the conditions that it requires and that it is able to meet thanks to equations (1.41 and 1.42). (Janakiraman, 2018)

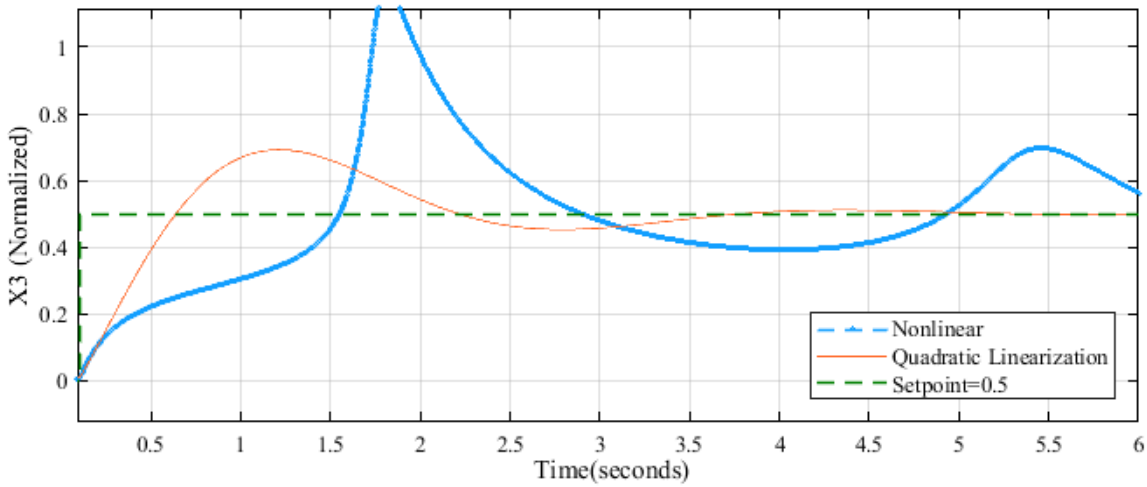

Figure 1.7: depicts the closed-loop step response for y3 (x3).

1.5.2. Discussion of Results

As a result of the data, we can see that the system was successful in reaching a stable state. However, the results continue to be unsatisfactory due to the fact that they were higher than the maximum peak value that was permitted, with the peak rise accounting for nearly 40% of the total values.

Although it is a revolutionary method that deserves attention, it has defects. Researchers make use of a difficult strategy to find modeling in this methodology. It is challenging to follow the stages that the researchers took in their investigation. However, the outcomes did not match what was expected. and it is challenging to understand each variable by itself.

1.6. COMPARATIVE BETWEEN PID CONTROL AND FUZZY LOGIC CONTROL

In the level tank system, a comparison between the PID control and the fuzzy logic control.

1.6.1. PID Control

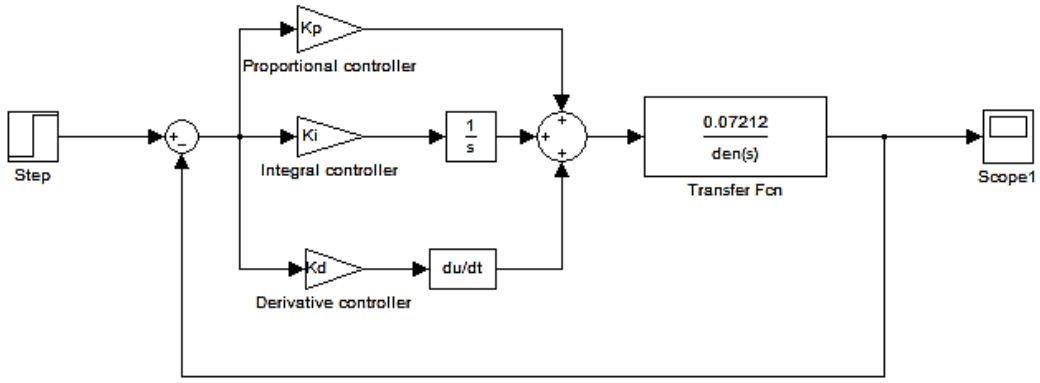

Figure 1.8: Simulation design for PID controller

Figure 1.8 illustrates a simulation of the PID controller. The difference for both the setpoint value as well as the measured variables is transmitted to the control. (Qingly,2013)

PID controllers identify the control actions of proportional, integrated, and derivation controller, where proportional controllers lower the system's rise time, integral controllers reduce steady-state error, and derivative controllers limit the system's overshoots. (Kumar & Nagpal, 2017).

The following parameter values were obtained (Kumar & Nagpal, 2017) for the P, PI, and PID controllers.

Table 1.1: parameters of P,PI,& PID controllers.

controllers	kp	ki	kd
P	328.3	-	-
PI	67.4	1.115	-
PID	67.4	1.155	10.7

1.6.2. Fuzzy Logic Controller

Fuzzification, fuzzy rules, with defuzzification are the components of Fuzzy controller. where the crisp inputs are transformed to fuzzy inputs through fuzzification. For this case, they selected valves as that of the output and rates and level as that of the inputs. The choosing of classifiers for variable input and output is the following step in the fuzzifications process.

Both input and output variables utilize the triangle membership function. now step is to choose a selection of variables subsets from the display range of variables.

Fuzzy logic controllers can be implemented in a variety of ways, including the Mamdani, Sugeno, and Lusing Larson approaches. They are employing the Mamdani approach in their controller design since it is the most widely used fuzzy method.

Here, they have used subsets of low, high, & okay for the error parameter, subsets of negatives, zero, & positives for the rates of change variables, and subsets of OF, OS, CF, CS, & NC for the valves variables.

The rules that are presented in the rules table can be stated in the following way:

Table 1.2: Fuzzy logic rules

level	low	okay	high
negative	open fast	open slowly	close fast
zero	open fast	no change	close fast
positive	open fast	close slowly	close fast

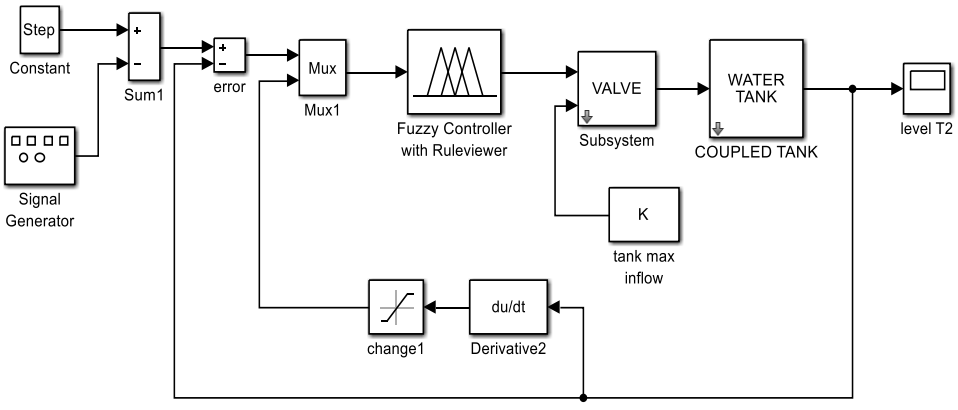

Figure 1.9: Simulation design for fuzzy logic controller

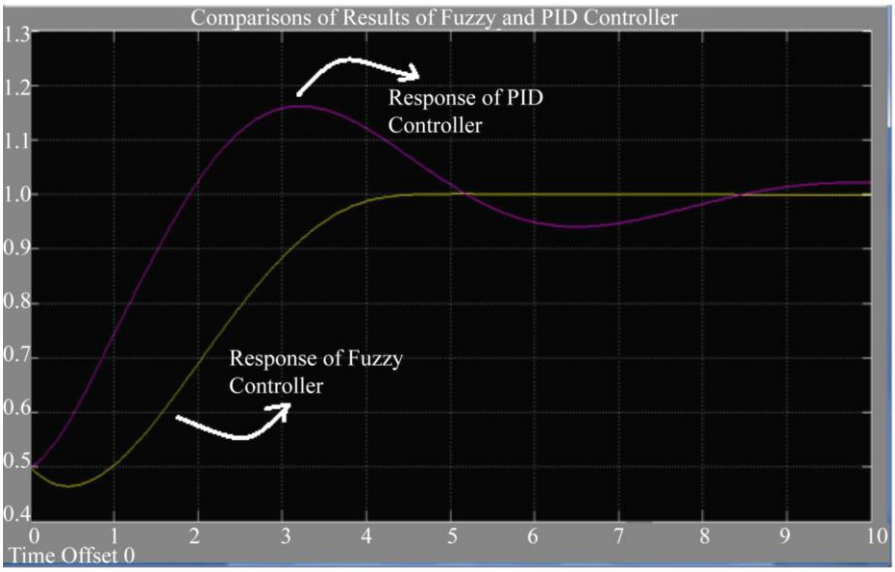

Figure 1.10: Fuzzy logic and PID simulated results.

The results demonstrate that, in general, fuzzy logic is ineffective, that its performance is significantly superior to that of the PID control, and that the peak value of the PID control is unacceptable at around 17%. This is an unsatisfactory value for control system engineering, and because this is quite simple must be a PID controller need tuning.

Table 1.3: Compare results between P, PI, PID, and Fuzzy Logic

Controllers	Rise time (sec)	Steady state error (Percentage)	Peak overshoot (Percentage)	Setting time (sec)
P	1.91	0.8	50	20
PI	1.40	1.5	19	16
PID	1.55	1.5	17	12
Fuzzy logic	3.27	0	0	5

Despite the difference between this system and the one we are working on, they are in the same field, and therefore we can say that intelligent control is superior to classic control. This gives us a good sense of the results that can be obtained from our system.

2. CONCEPTUAL FRAMEWORK (CONTROL SECTION)

2.1. OVERVIEW

Inside this chapter, we provide a comprehensive review of control theory and describe how each component of a control system differentiates from the other components. Here are several ways we approach this:

With regard to the system, the system signal, and the user controller. There are several topics that cannot be avoided while discussing the control system. These are foundation in control systems. systems are classified in terms of the way the signal is transmitted the open loop and closed loop system, and in terms of mathematical analysis and in terms of mathematical analysis divides frequency domain and time domain.

In terms of the number of inputs and outputs of the system, single input single output SISO and multi-input multi output MIMO, when we talk about the behavior of the system, it is divided as follows linear system and non-linear system. The stability of a system in a linear system depends on the poles and zeros. The stability of the system in the nonlinear system depends the condition of the input as well as the initial state. Classification of systems is dependent on whether input and output signals are digital and continuous.

Types of controllers can be classified into two primary types: classic control and modern control. Classic control ON-OFF control and PIDs control. As for modern controllers, they classify multiple methods we can choose one of them. Adaptive control Hierarchical control, Intelligent control, Non-Linear control, Optimal control, Robust control, Stochastic control.

We are interested in PID control and intelligent control because we will utilize them frequently. It is planned to make use of controllers of the P, PI, PD, and PID types. In this research utilize intelligent control, fuzzy logic control, neural networks control, adaptive control, and ANFIS control.

There is no specific classification in all the researcher on how to classify the controllers, but we can find some similarities in those classifications, most of which specify a division between them as "classic control," "modern control," One of these classifications is presented in the chart

that follows. This classification splits controllers into two main classifications: the classic control and the modern control.

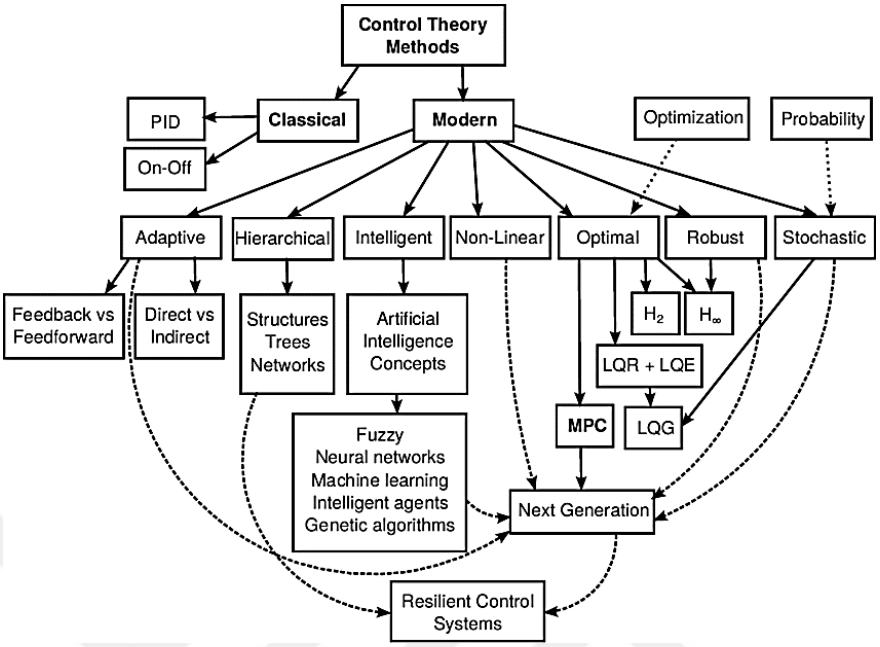

Figure 2.1 control classification

2.2. CONTROL THEORY

A subfield of mathematical logic called control theory focuses on managing dynamical operating system. Building a control modelling with a quick response, no overshoots, and systems stability are all goals of the control theory. Examples of such systems include machines. Our modern lifestyles have been significantly improved by automation. The control theory, as is well known, is the basis of the industrialization and is transforming all industrial plants into completely automated ones.

2.2.1. Open Loop Control Systems and Closed Loop Control Systems

Open-loop control system and closed-loop control system are the two primary classifications of control systems. Open-loop control systems are those in which the action that is performed by the controller is not dependent on the outputs of the process. An open loop control system might be used for something as straightforward.

2.2.1.1. Open-Loop Control System

As depicted in Figure 2.2, this type of control system consists of a control action that is totally dependent on the inputs signal and do not depend on the outputs it receives from the systems it is controlling.

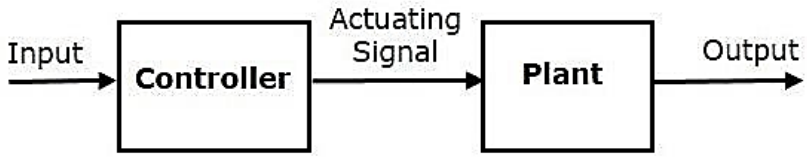

Figure 2.2 open loop control system

This method offers a number of benefits, including the fact that it is straightforward, easy to comprehend and design, as well as low-cost and uncomplicated to use and maintain. However, it does have a few disadvantages, such as the fact that it is inaccurate and that we need to check its results at regular times. Additionally, it is utilized in a few locations, such as washing machines and traffic light signals.

2.2.1.2. Close Loop Control System

As can be seen in Figure 2.3, this device is a control system in which the controller action depends on both the input signal and the reaction from the output.

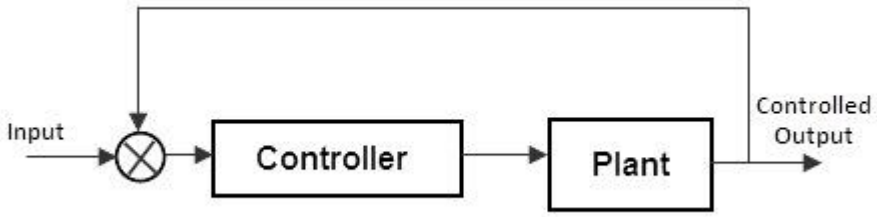

Figure 2.3 close loop control system

We can make any open-loop control system into a closed-loop one by incorporating a feedback loop into the design. The input in these control systems is regulated by the feedback signal that is received from the input, which allows it to fix any errors that have been made.

The feedback loop enables an automatic correction to be made to the signal being input based on the requirements being imposed by the output. Closed-loop control systems are designed to

produce an error signal if there is a deviation between the decided actually output and the produced output. This error signal is then sent to the input of the signal.

A- Advantages of system

a functioning that is more accurate than that of a control system with an open loop. It is possible for the system to function effectively when the input or system characteristics are variable. In these systems, the effect of nonlinear dynamics on output response is significantly reduced. high capacity for information transfer. In addition to that, there is the possibility of using automation. There is no need to do occasional correction of the parameters in this technique.

B- Disadvantages of system.

Complex design and challenging to manufacture, compared to an open-loop control system, this system is more expensive. difficult to maintain comparative analysis of open-loop versus closed-loop control systems:

It refers to a control system in which the control action is dependent upon both the input signal and the output reaction.

Table 2.1: Comparison between closed loop and open loop control systems

Open loop system	Close loop system
The control system does not receive any feedback at all	This control systems receives feedback.
is unable to be intelligent	Intelligent controllers can be implemented
There isn't any prospect of the system oscillating in an undesired manner.	Unwanted systems oscillation is a potential with closed-loop control.
In the event that the system parameters do not undergo any changes, the outcome will not be very stable.	Based on the feedback, the system's output could change for an input that remains constant.
The degree to which the output of the system varies as a result to changes in the parameters of the system is increased, and the output cannot be controlled.	Less variance in system output results from changes in the system's parameters.
inexpensive	costly
Simple structure	complicated designs

2.2.2. Representation In Time and Frequency Domains

transfer function of systems can be presented in two different ways: within time domain or within frequency domain. Due to the limitations of frequency domain techniques, nonlinear systems are presented in the time domain. The variables that represent the system's inputs, outputs, and feedback are described as functions of frequency with in frequency domain.

Algorithms are made simpler by some computer program like MATLAB. The transfer function could be created using the physical structure's information’s. Some transformation techniques, including as the Laplace transformation technique, Fourier transformation technique, and Z transformation method, can change the system's values from the time domain to the frequency domain.

2.2.3. Continuous Time and Discrete-Time Control Systems

Control systems operating in both continuous time and discrete time

Control Systems are able to be broken down into two classifications, continuous time control system and discrete time control system, according to the kind of signal that is applied.

In control system that operate in continuous time, each of the signals operates in a manner that is continuous in time. However, there can be anywhere from one to several discrete time signals present in a discrete time control system.

2.2.4. Types of Feedback

Positive feedback and negative feedback are the two categories that fall under the feedback category.

2.2.4.1. Positive feedback

The reference input and the feedback output are both added by the positive feedback. The schematic representation of a positive feedback control system can be found in the accompanying figure.2.4.

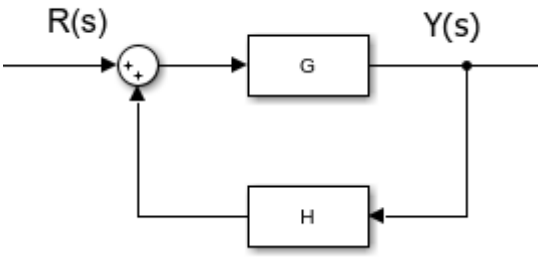

Figure 2.4 Positive feedback.

2.2.4.2. Negative feedback

The error that exists between the reference input and the system output can be reduced through negative feedback. The block diagram of the negative feedback control system is depicted in the figure.2.5 that can be found below.

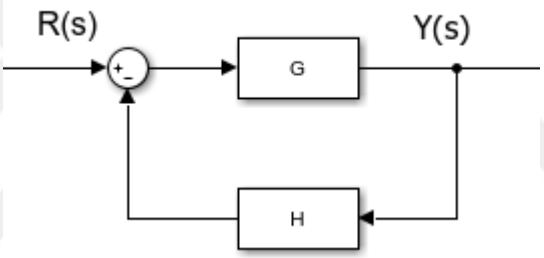

Figure 2.5 Positive feedback.

Statistical Method for Evaluating Stability

That ability of a particular system to reach the stable state after successfully navigating through a series of transients is what is meant by the term "stability."

2.3. PID CONTROLLER

An automatic optimization and precise control system called a proportional, integral, and derivative PID controller is used to maintain desirable values for a variety of parameters, including temp, flow rate, and velocity.

Control loop feedback is the fundamental mechanism utilized by PID controllers. By calculating the difference between the current values and the desired values, a PID determines the error and then adjusts the determining parameters as necessary. Until the process is finished, the errors are continuously calculated.

PID (Proportional - Integral - Derivative) Control was initially created as manually adjustable motor governors in the 1890s. Nicolas Minorsky, who was employed by U.S. Navy at the time, wrote the first theory of PID control in 1922.

Since the 1940s, first publications on PID tuning were published. There are thousands of distinct tuning rules for PID controllers (Dwyer, 2009). 97 percent of regulated controllers today use PID feedback. According to a survey of more than 11,000 controllers from the refining, petrochemical, and publishing industries (Desborough and Miller, 2002).

The block diagram for PID control and signals is shown in Figure 2.6.

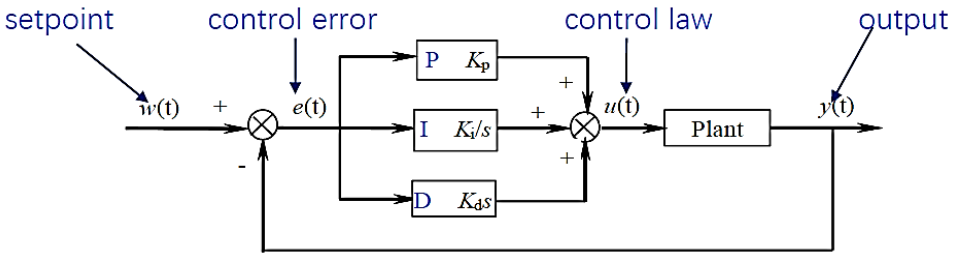

Figure 2.6 PID block diagram

In this part of section PID control will be discussed.

As an example, consider a second-order system. As shown by the following equation:

$$f(s) = \frac{1}{10s^2+7s+1} \tag{2.1}$$

2.3.1. Proportıonal (P) Controller

Proportional (P) Controllers are typically utilized in first-order systems that only have one power source storage in an effort to bring stability to otherwise unstable systems. The steady-state error of the system is the primary focus of the P controller, whose primary mission is to reduce that error. The steady state inaccuracy of the system will decrease in proportion to the gain factor K's increasing value. Nevertheless, in spite of the improvement, P control will never be able to eradicate the steady state error that exists within the system.

As the proportional gain is increased, the system produces a smaller magnitude and phase margin, quicker dynamics that fulfill a wider frequency spectrum, and a higher sensitivity to noises. The controller would be only available to us to utilize when our systems are able to tolerate an error in a constant steady state.

In fact, it is simple to draw the conclusion that raising P reduces total rise time, and that after a certain value of reductions in the steady state error, increasing K actually leads to overshoot of the response of the systems. Both of these results are supported by the evidence. Oscillation can also be caused by P control if it is implemented in a manner that is excessively forceful in the presence of lags and dead time.

The more lags, or higher orders, anything has, the more problems it will lead to. Additionally, it does a direct amplifying of the process noise.

The P controller can be represented by the following equation:

$$u(t) = K_p e(t) \qquad (2.2)$$

The system blocks diagram can be designed as shown in Figure 2.7.

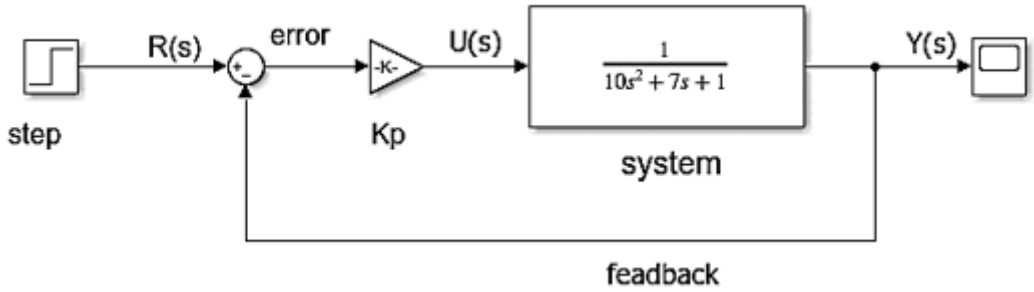

Figure 2.7. The P controller system blocks diagram

Additionally, we can display the system's results in a closed loop using MATLAB. Figure 2.7 shows the results of the closed-loop system using the P controller.

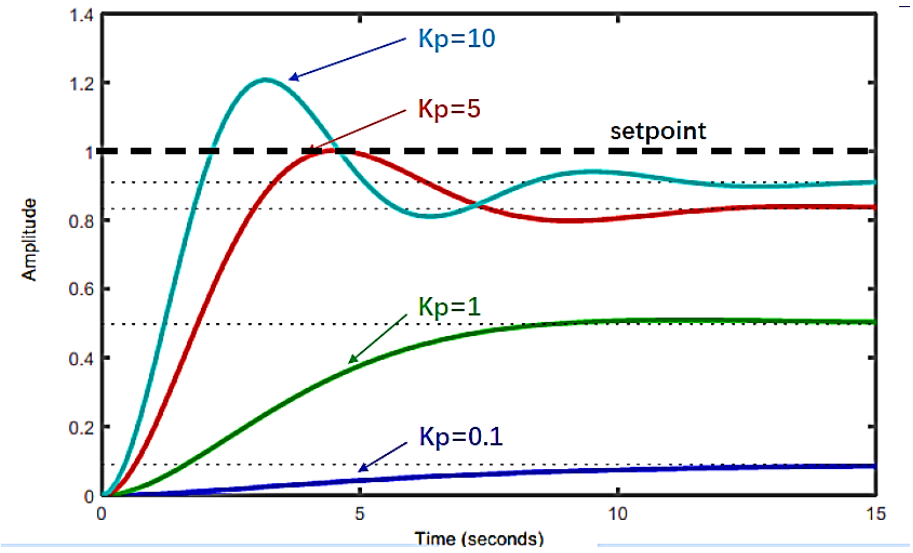

Figure 2.7. P controller system response

According to the results, we can say that When K_p is increased, the response speed of the system is also increased, as is the overshoot of the closed-loop system, while the steady-state error is decreased. If K_p is made sufficiently large, the closed-loop system will become unstable.

2.3.2. PI Controllers

The primary purpose of PI controllers is to eradicate the steady-state error that is brought about by P controllers. On the other hand, this has a detrimental effect on the system's responsiveness as well as the stability of the systems. The majority of applications for this controller are found in domains where the speed of the systems is not a primary concern.

Because the PI controller is unable to anticipate the future errors that will be generated by the system, it is unable to reduce the rise time or get rid of the oscillations. If it is implemented, any amount of I will guarantee that the fixed point will be exceeded. (Åström 1995)

The PI controller is represented by the equation below:

$$(t) = K_p e(t) + K_i \int_0^t e(t)\, dt \tag{2.3}$$

The following equation shows the control signal in the PI controller:

$$U(s) = (K_p + \frac{K_i}{s})E(s) \tag{2.4}$$

Figure 2.8 shows how to construct PI controller system blocks diagram.

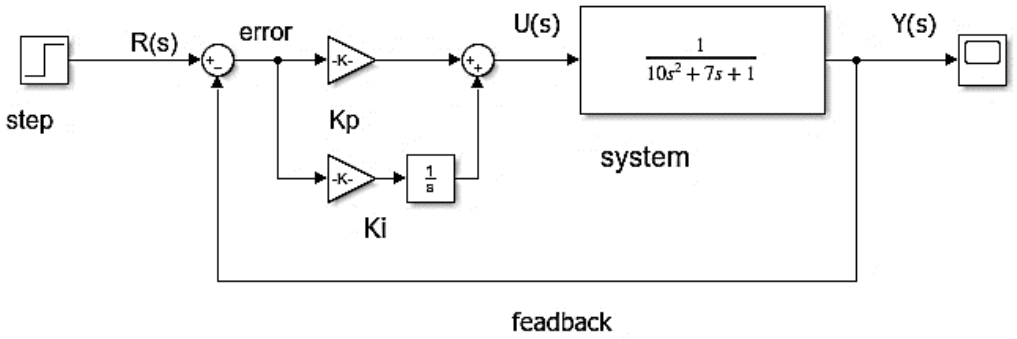

Figure 2.8. The PI controller system blocks diagram

We can utilize MATLAB to present the results of the system in closed loop. The results of the closed-loop system that was controlled by the PI controller are shown on Figure 2.9.

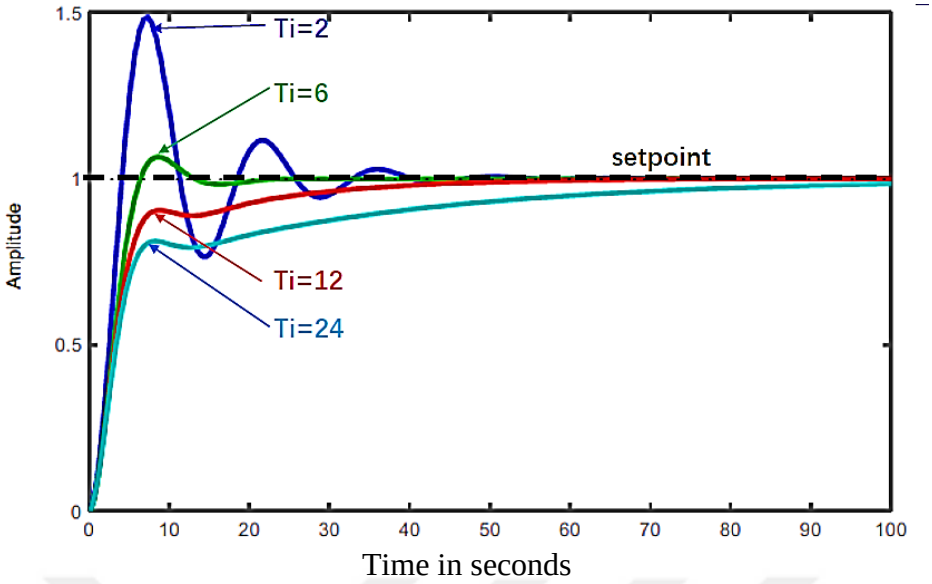

Figure 2.9. PI controller system response

Ti is responsible for the proportional and integral control action, while kp is responsible for the integral control action. The PI controller combines the beneficial aspects of both the P controller and the PI controller into one convenient package.

The response time decreases as a result of the P controllers, but it shortens as a result of the I controller, and the steady-state error disappears entirely. As T_i is increased, the damping factor is likewise increased; as a result, big oscillations caused by the P controller can be made smaller by decreasing their amplitude.

2.3.3. Proportional Derivative (PD) Controller

Using the PD controllers have the potential to anticipate future faults in the system's reaction, which improves control and aims to increase system stability. That derivative is obtained from the output's response of the systems variable rather than the error signal in order to avoid the impacts of the error signal's rapid change in value. In order to prevent abrupt changes in the control output brought on by abrupt change in the error signal, D method is created to be proportionate to the change in the output's variable. D only controller is not utilized since D also enhances systems noise directly.

Fast responses are produced by PD controller. The offset is also produced because it is unable to control the steady-state inaccuracy. The steady-state error could not be decreased by the PD controller.

PD controller improve transient, dampen response oscillations, and raise damping. As a result, it may increase system stability. Additionally, PD controller enhance noise and could result in an actuator saturation effect.

The PD controller can be represented by the following equation:

$$u(t) = K_p e(t) + K_d \frac{d}{dt} e(t) \tag{2.5}$$

The control signal in the PD controller is shown in the equation below:

$$U(s) = (K_p + K_d s)E(s) \tag{2.6}$$

As shown in figure 2.10 below, we can construct a block diagram for a PD controller closed loop system.

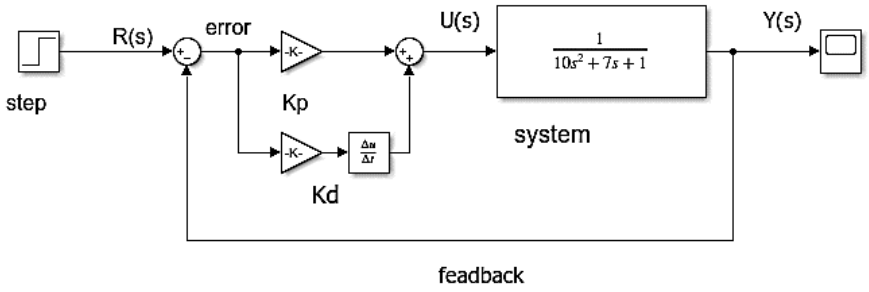

Figure 2.10. The PD controller system blocks diagram

To display the system's closed-loop findings, we can use MATLAB. Figure 2.11 displays the outcomes of the closed-loop system that the PD controller monitored.

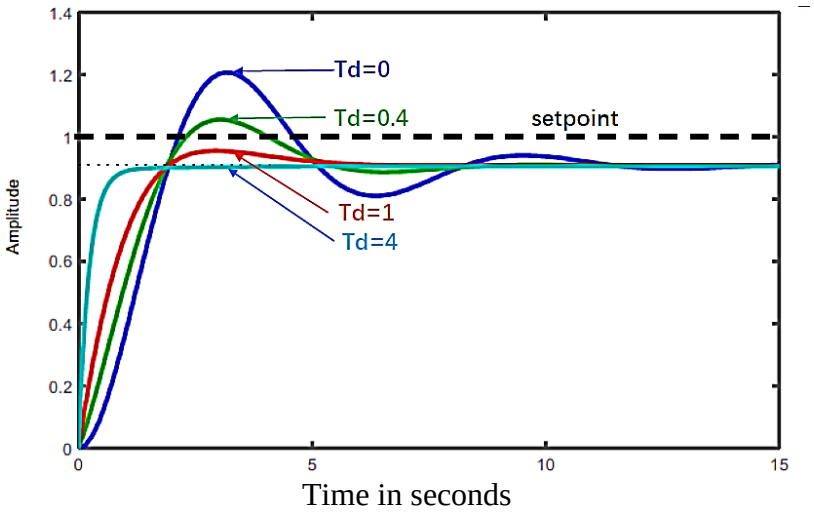

Figure 2.11. PD controller system response

It is clear from the display of the result that there is a difference between the set point value and the end value of the system. And its significance is that the steady state is inexcusable since the damping is high.

2.3.4. PID Proportional Integral Derivative, Controller

PID meaning Proportional Integral Derivative, controller. The PID controllers are extensively utilized since it is simple to comprehend and extremely effective.

One of advantages of the PID controllers are that all designers are familiar with concept integration & differentiation allowing them to design the control systems without a strong overview of control theories.

Moreover, although compensator is basic, it is highly clever because it captures the system's history by integration and predicts the system's future behavior through differentiation.

We will explain the impact of every PID parameter on the dynamic of a closed loop systems and explain how to utilize a PID controller to enhance the performance of the systems.

PID controllers feature optimal control dynamic, with zero steady-state error, quick reaction small rise time, absence of oscillations, and increased stability. In furthermore to PI controllers, derivative gain component is required to prevent overshoot and oscillation from arising in the system's outputs response.

One of primary benefits of PID controllers is that they could be applied to third - order or higher more systems with multiple energy storages.

The following equation can be used to describe the PID controller. It is clear from the equation that there are three components, and It is the sum of the PID's three parameters, proportional, integral, and derivative

$$u(t) = K_p e(t) + K_i \int_0^t e(t)\,dt + K_d \frac{d}{dt} e(t) \tag{2.7}$$

The equation below illustrates the control signal in the PID controller. It is the sum of the calculations for the three controller parameters multiplied by the error percentage.

$$U(s) = (K_p + \frac{K_i}{s} + K_d s)E(s) \tag{2.8}$$

As shown in figure 2.12 below, we can construct a block diagram for a PID controller closed loop system.

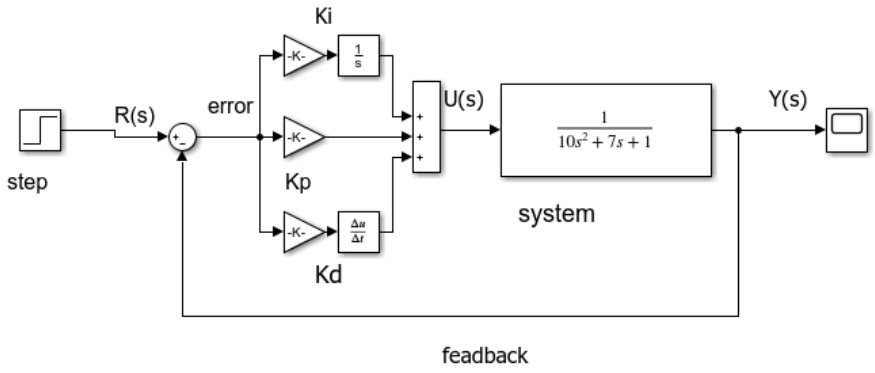

Figure 2.12. PID controller system response

MATLAB can be used to display the system's closed-loop results. Figure 2.12 shows the results of the closed-loop system controlled by the PID controller. Although it is possible to display all parameters in a single block diagram, we choose to collect them individually to simplify understanding of the controller's activity.

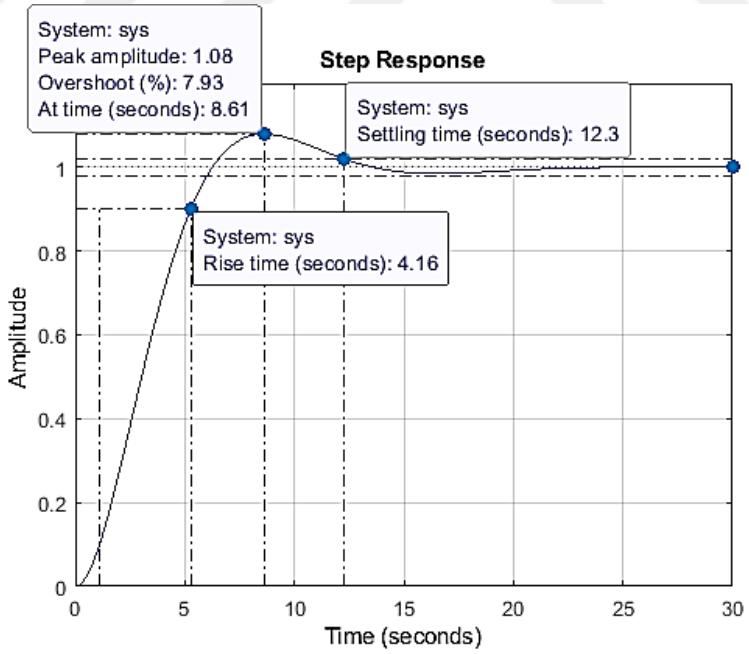

Figure 2.13. PID controller system response

Through the results of the controllers P, PI, PD, and PID, it is clear to us that the controller PID has the best performance among the rest of the types of controllers, but this does not mean that the rest of the types of controllers are not used in some systems, depending on the needs of

those systems for the controller itself. This is due to the characteristics of the controller which system's needs.

2.4. FUZZY LOGIC CONTROL

The Fuzzy logic is comparable to how we feel and infer in humans (Zadeh). The accompanying membership functions are used to fuzzified the input and result of the fuzzy controllers to produce the output.

Nobody barely notices fuzzy concepts or fuzzy logic because they are used so frequently in daily life. Computer can only comprehend the numbers 0 or 1, as well as high or low (Mamdani 1974). Approaches employing fuzzy logic have been frequently used in facets of industry.

These three major stages are necessary to apply fuzzy logic to a real application: Fuzzification, which involves turning crisp or classical data into fuzzy data or Membership Functions MFs.

The fuzzy outputs are obtained through the fuzzy inference method, which combines membership functions and control rules. For an actual system, fuzzy controls are a process of crisp fuzzy crisp.

The intermediate method is a fuzzy inference process, but the initial inputs and the final outputs must be crisp values. Real applications typically include inputs variables with multiple dimensions, necessitating either fuzzification or the development of a Membership Function for each dimension variables individually (Mamdani 1974).

2.4.1. Historical Overview

The first paper was published in 1965 by Lotfi Zadeh and proposed fuzzy logic (Zadeh). And From Japan, fuzzy system was first deployed. In an "inverted pendulum" research study, Takeshi Yamakawa showed the application of fuzzy control via a set of specialized fuzzy logic circuits.

The fuzzy control systems of Sony's cameras include Twelve inputs to detect lens movements. The United States Environmental Protection Agency has examined fuzzy control for power efficient motor, while NASA had also investigated fuzzy control with automatic space docking (Pedrycz 1993).

In addition, Japanese have activity on fuzzy system. in the United States and Europe had a huge work in fuzzy logic area. Airbus, Exxon Mobil, Phillip, Daimler, Siemens, and Samsung have created fuzzy logic (Sarabadani 2015).

The "smart" dishwasher manufactured by Samsung utilized the fuzzy logic controllers and “one-stop sensor module." Xiera Tech created first auto-tuner for the edeX base of knowledge of the fuzzy logic controllers. The ultimate objective of developing "self-learning" fuzzy logic control mechanisms is to stabilize and control, complex, nonlinear, and robust systems (Lugli 2016).

2.4.2. Fuzzy Logic and Fuzzy Sets

As overall, set of membership function resembling these are used to map inputs variables in fuzzy control systems, or fuzzy sets. Fuzzification are the technique of transforming a crisp input value into a fuzzy value. The construction of two fuzzy systems, one for errors direction angle and another for speed control, took the fuzzy logic-based method into consideration.

In addition to its analog input, a control system could also contain different kinds of relay, or on off, inputs. These switch inputs will always have truth values equal to another One or zero, but the schemes could handle these as streamlined fuzzy function that happens to be almost one values or the zero.

The microprocessor determines what actions to do after receiving mappings of input variable into membership function and truth value based on a set of rules, each of which has the general formula:

$$\mu A(x) = \begin{cases} 1 & x \in A \\ 0 & x \notin A \end{cases} \tag{2.9}$$

$$\mu A(x) \in \{0,1\} \tag{2.10}$$

As demonstrated in Equation 2.11, the idea of Fuzzy Sets is that expands the limit of memberships to an unlimited limit.

$$\mu A(x) \in [0,1] \tag{2.11}$$

2.4.3. Difference Between Crisp Set and Fuzzy Set

Crisp sets and fuzzy sets are two different sets ideas, where crisp sets use bi values logic while fuzzy sets used infinite values logic. Expert system concepts are originally developed on the

basis of Boolean algebra, which crisp sets will be used. Then again, scientists countered, human thought might be hazy, subjective, unclear, imprecise, or fuzzy in character and not always follow clear cut yes-or-no logic. This launched the fuzzy sets theory's development as a way to simulate human thought.

Figure 2.14. displays two sets to illustrate the concept of Fuzzy memberships. Define the universe to consist Set one, which is the crisp set, and Set two, which is the fuzzy set.

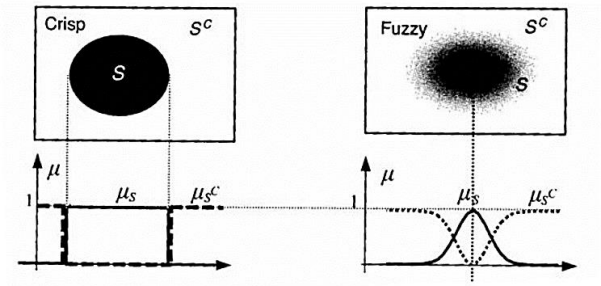

Figure 2.14 one crisp set and two fuzzy set

The fuzzy set concept is explained by a math equation, which can be obtained in the equation 2.12

$$E = \{(x, \mu E(x)) \mid x \in F, \mu E(x) \in [0.1]\} \quad (2.12)$$

2.4.4. Fuzzy Set Operations

The systems with inputs x, y, and z and an output variables n are shown with max min inferencing and center defuzzification below. Note that mu are the accepted term meaning truth value in fuzzy logic

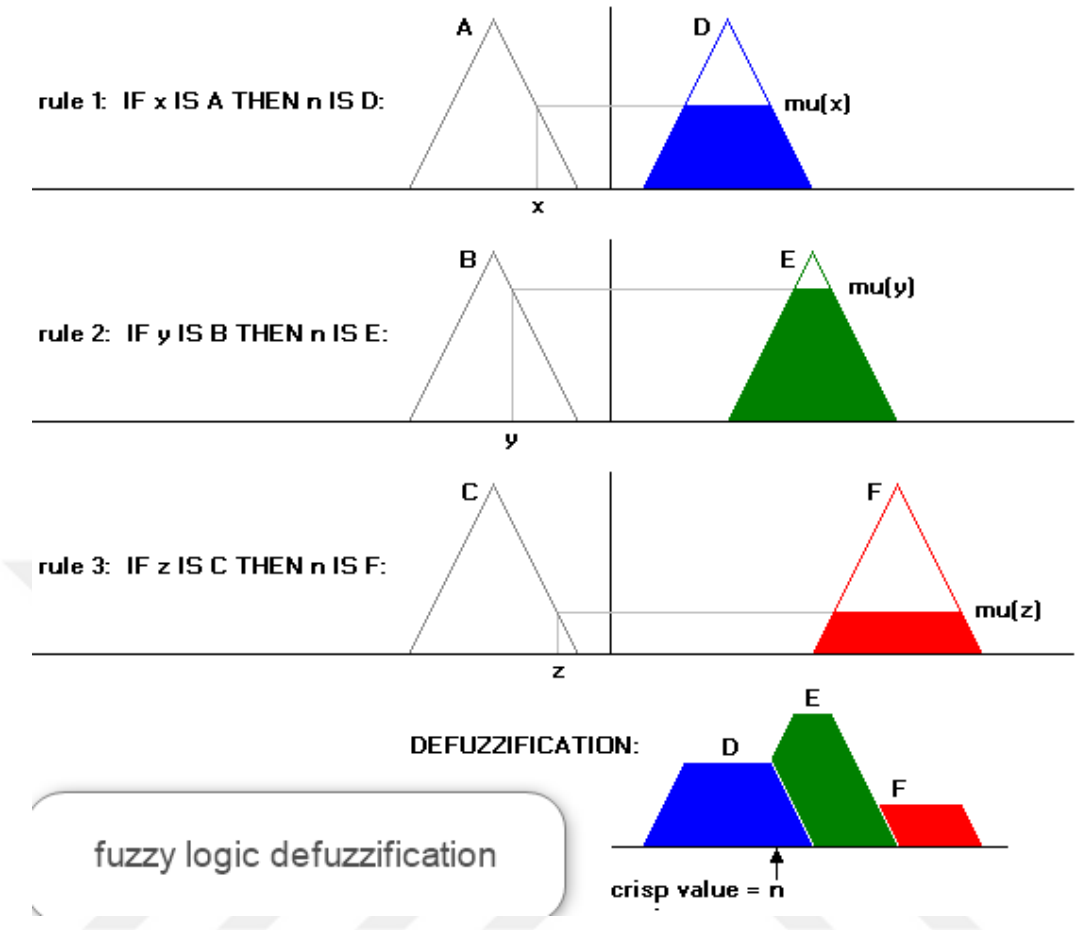

Figure 2.15 fuzzy logic defuzzification

2.4.5. Fuzzification

Designing fuzzy control systems depends on empirical techniques, which are essentially a systematic version of trial and error. The standard method goes like this:

write the input, output, and proposed feature for the system.

Write the fuzzy set for the input.

Write the rules set.

Choose a defuzzification technique.

Start test cases to verify system make necessary adjustments to detail.

Write the statement, then send it to manufacturing.

Consider the development of a fuzzy controller for one combustion engine as a generic illustration. The below is the blocks diagram for the control system:

There are two inputs variables one for temperature and anther for pressure

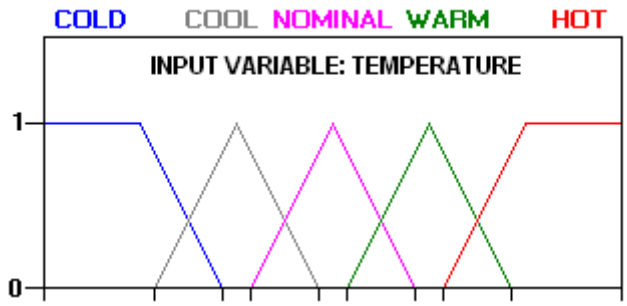

Figure 2.16 input one temperature

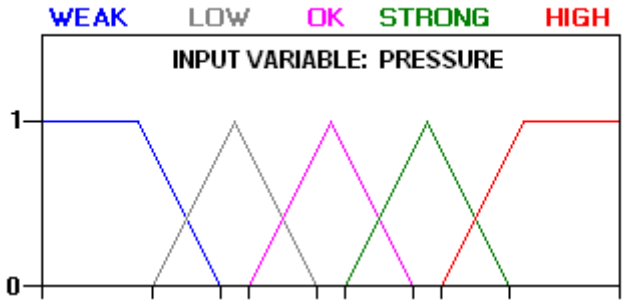

Figure 2.17 input two pressure

The out variables setting N3: high close, N2: Medi close, N1: little close, Z: no change.

P1: little open, P2: Medi open, P3: high open.

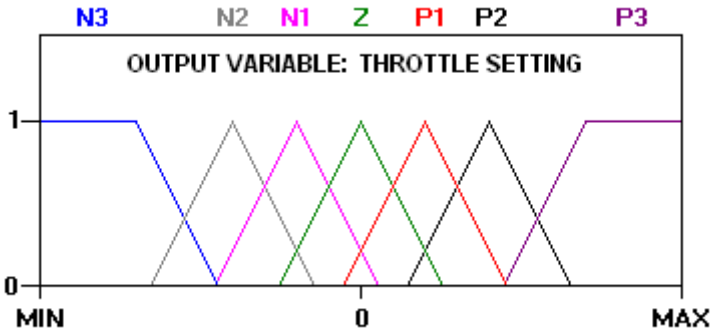

Figure 2.18 output variable

2.4.6. Fuzzy Set Rules

The condition of fuzzy logic is determined by fuzzy rules. It is a similar technique to the fuzzification technique.

- 1. If (Error is HN) then (Controller is Closed) (1)
- 2. If (Error is HP) then (Controller is Open) (1)

- 3. If (Error is N) and (change error is HN) then (Controller is Closed) (1)
- 4. If (Error is N) and (change_error is N) then (Controller is Closed) (1)
- 5. If (Error is N) and (change_error is z) then (Controller is Simi_Colsed) (1)
- 6. If (Error is N) and (change_error is p) then (Controller is Middle) (1)
- 7. If (Error is N) and (change_error is hp) then (Controller is Middle) (1)

2.4.7. Summary of Fuzzy Logic

The basics of fuzzification, defuzzification, and fuzzy rule systems are discussed in this part in detail. Starting with crisp set or fuzzy sets and the operations associated with them, researchers developed fuzzy set and the operations associated with them.

Following the discussion of fuzzy sets, a detailed look is given to both traditional set membership function as well as fuzzy set membership function. An application of fuzzy rule can be seen in action in the control of a heating system.

In conclusion, a number of other fuzzy procedures are addressed. These techniques include off-lines as well as online fuzzy control system, in addition to the fuzzy closed-loop control systems that incorporates numerous formulas. The introduction of innovative fuzzy methods will undoubtedly result in the control of fuzzy systems playing an ever-increasingly significant part in our daily lives.

2.5. NEURAL NETWORKS (ANN)

Artificial neural networks (ANN) provide an ideal machine learning methodology. Real, discrete, vector-valued functions are suitable to ANN learning by example. The ability of ANN to tackle problems including robotics control algorithm, speech recognition, and imagery recognition has been demonstrated. The ANN learning technique offered a robust reaction to mistakes based on the available training data. An essential characteristic of ANN is that it can operate as a predictor for real-world issues such as measured data. It can facilitate successful learning techniques. The "Backpropagation" algorithm is a popular ANN algorithm. Backpropagation has indeed been effectively applied to learning challenges such as the recognition of handwritten characters, spoken phrases, and faces.

2.6. ANFIS

ANFIS (Adaptive Neuro-Fuzzy Inference System) is the teaching technique for fuzzy system of the Sugeno class. The assistance of ANFIS identifies process variables. When using ANFIS, the user typically defines the number and kind of fuzzy systems membership function.

The ANFIS-method is a hybrid approach that includes two steps: the Gradients method is used to calculate the values of the input's membership functions, and the least squares method is used to calculate the values of the outputs function.

The limitations of the MATLAB and Simulink ANFIS-method are as follows:

- just Sugeno kind decision methods are accessible and just one result is allowed

- Weighted mean values defuzzification are the method used.

There is a handy technique named ANFIS in the fuzzy logic control toolbox. This offers a method of optimizing for locating the fuzzy system's variables which best match the data. The Toolbox handbook explains that as most (but not all) optimization techniques call for computing the gradients, neural networks are used to carry out these tasks. So, theoretically, any optimization strategy, like those found in MATLAB Optimization Toolboxes, may be applied.

The installation of ANFIS in MATLAB, the connections between the input and output, and the layers that go between them are depicted in the accompanying figure2.19.

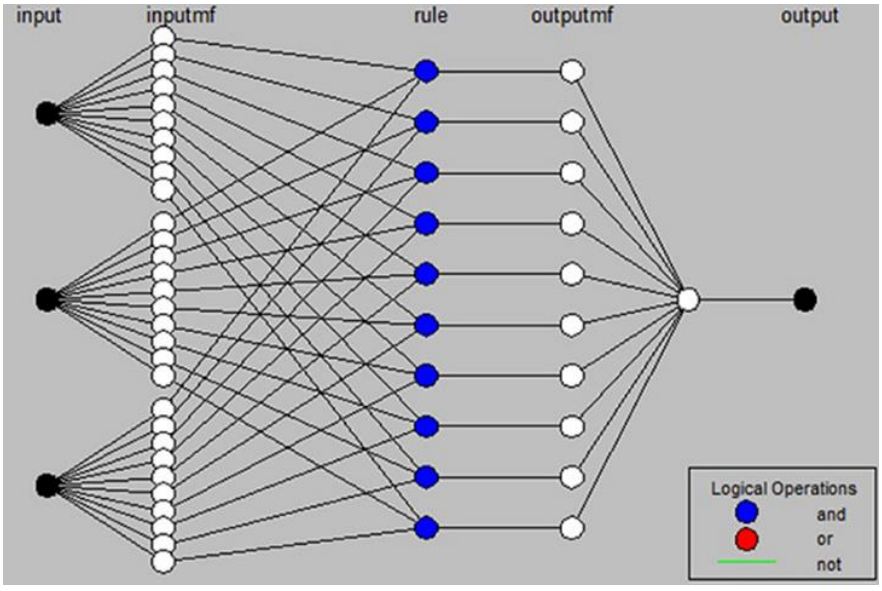

Figure 2.19 ANFIS installation in MATLAB

2.6.1. ANFIS Construction

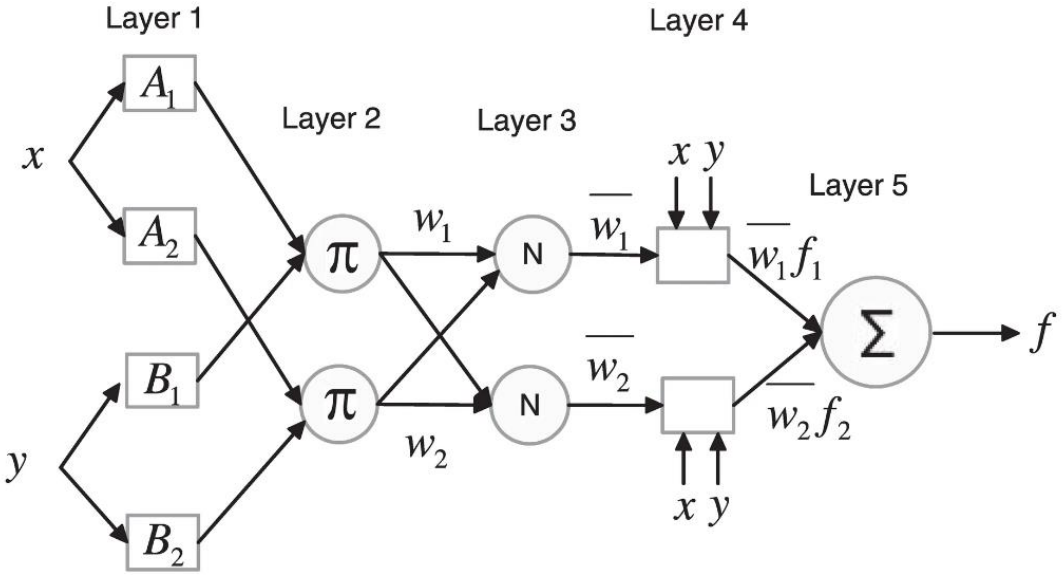

Figure 2.20 ANFIS layers

Layer 1: Each nodes *i* within that layer has a node functions and adaptive node.

These variables are known called premises parameters.

Layer 2: Each nodes in that layer bears the label Production.

Layer 3: Each layer has only static nodes called Normal.

Layer 4: Those are all known called consequential variables.

Layer 5: Each solitary nodes in that layer are fixed nodes called sum that calculates the outputs as that of the total of all input signals:

$$O_{5,1} = \sum_i \overline{w_i}\, f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \tag{2.12}$$

There are further constructions.

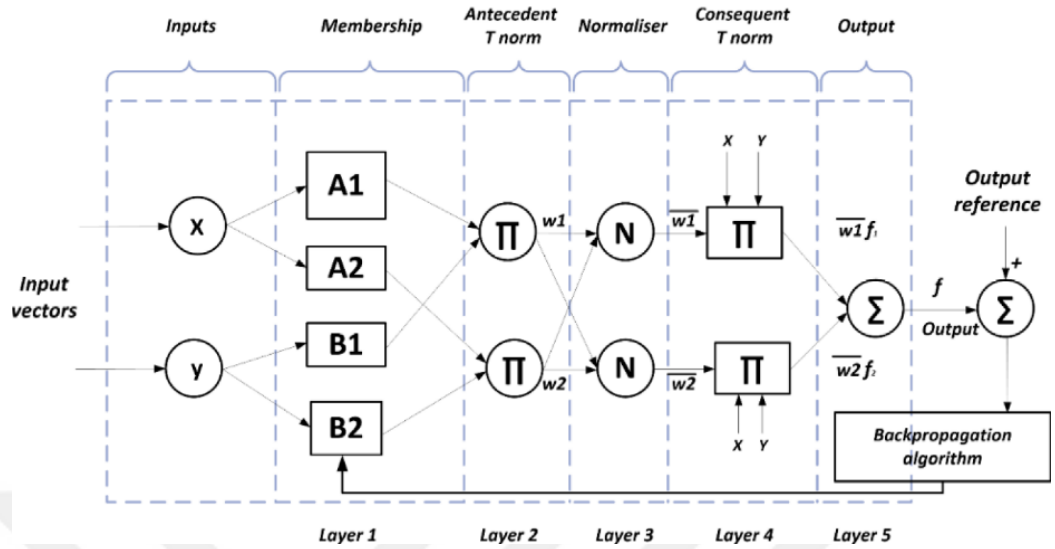

Figure 2.21 construction ANFIS layers

3. METHOD

3.1. A THREE-PHASE GRAVITY SEPARATOR DESCRIPTION

As its name suggests, Separator is designed and produced to separate a number of different things. Natural gas, crude oil, and wastewater are the three things that are produced in not equal proportions by an oil production plant. As an additional medium, some oil industrial plants may contain sand and other materials. The design decisions that can be taken for separators are influenced by a number of factors, including the components of the input flow as well as the amount of space that is available within the plant. When it comes to gravity separators, lying tanks and standing tanks are both appropriate layouts. This thesis investigates three phase separators for crude oil, natural gas, and wastewater that is built in the form of a horizontal chamber and has one flow consumption and one flow passage for each product, as seen in Figure 3.1.

These separators are constructed in the form of a horizontal chamber because it was found to be the most efficient way to separate these three fluids. This particular separator has the shape of a horizontal chamber in its construction. Separation for wastewater, natural gas, and crude oil shown in figure 3.1 (Devold, 2010)

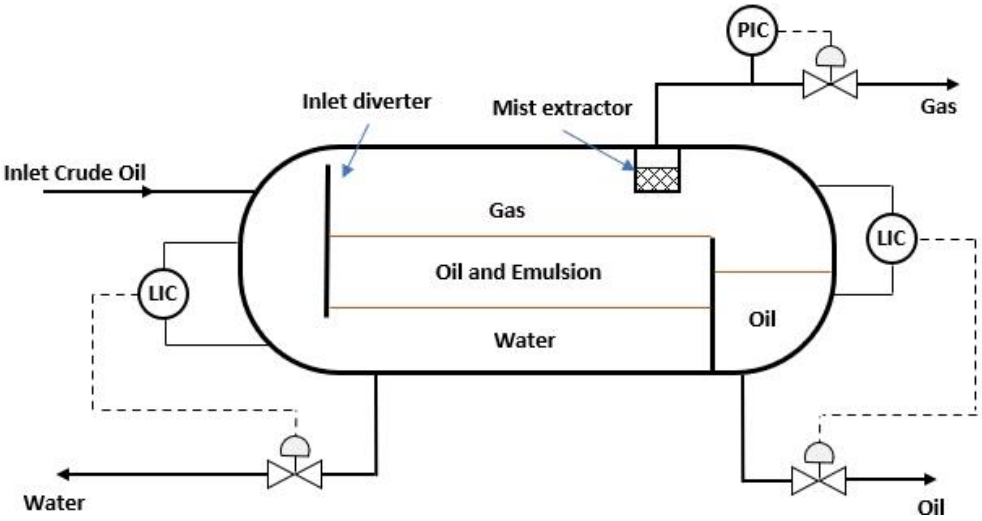

Figure 3.1 A diagram of one form of the horizontal cylindrical shape structure inside a three-phase gravity separator

The concept of gravity is used in the production separator that is under consideration. It indicates that the substance with the greatest density, which in this situation is wastewater, will fall to the bottom, and the less heavy natural gas will float to the top of the separator because of its lower density.

The crude oil, which will remain in the center of the separator, passes over a wier before being extracted from the separator's outlet. (Utdanningsdirektoratet 2011)

There is a slug catcher located at the entrance of the inlet, which lessens the impact that slugs have. A huge gas bubble or a liquid blockage that creates significant disruptions in the operation is referred to as a slug.

The demister's purpose is to collect any liquid droplets that may be existing in the gas. It is essential for subsequent processing units that the gas be as dry as is feasible. Droplets in the gas might cause damage to the compressor, which is necessary for extracting gas.

The chamber that contains the oil intake and the chamber that contains the oil outflow are going to be separated by the wier. A vortex breaker is attached to each liquid exit on the system. When the level of the liquid drops too low, the vortex breaker's job is to stop gas from leaking out via the outflows into the surrounding space.

3.2. THE MODEL OF THE PROCEDURE GRAVITY SEPARATOR.

There are three quantifiable process variables in the analytical separator procedure, wastewater level in the bottom, crude oil level, and natural gas pressure.

Each state's model is based on a physical rule and a geometric form known as a separator. Taylor and Sayda (2007). Also cited in Schei, Singstad and Thunem (1991), are studies in which comparable separator models are constructed, and the model in this thesis is based on those works.

Because it is more accurate than other hypotheses. Flashing is not included in the model, although it is accounted for in the mass balance calculation. For this task's derived process, net inflow and net outflow are equivalent for each component.

The term "flashing" is denoted by the factor Z when considered in the context of the masses balance equation. The research that was carried out by Schei. (1991) investigates the nonlinearities that are caused by flashing.

3.3. GRAVITY SEPARATOR GEOMETRY

Typically, separators are designing as a horizontal cylinder, as is the case with the studied plant. At (Wilhelmsen 2012), it is believed that the oil portion has simple walls. For the studied separator in this thesis, the geometry of the separator is taken into account, but the end sections are assumed to be simple walls.

When designing a short separator with a large radius, it is essential to take into account the end pieces, which are typically curved in shape.

The calculation of the cross-section type of the liquid level is shown in Figure 3.2. Equations for determining the liquid cross section type and the segment area of a circle. The formula for the cylinder radius is.

$$r = d/2. \tag{3.1}$$

It is well known that the liquid surface varies depending on the liquid level. The equation uses the Pythagoras formula to compute the breadth of the liquid surface (3.2). The radius is represented by r, the liquid level by h, and the distance between the liquid level and the tank center by α. Half the width is represented by β. (Kristensen, 2008). A sketch of the separator cross section type with the parameter targets is shown in Figure 3.2.

The equation below can be used to get the radius of the circle:

$$r^2 = \alpha^2 + \beta^2 \tag{3.2}$$

Additionally, β may be computed, and the following treatment determines the liquid's surface in the separator.

$$\beta^2 = r^2 - \alpha^2 \tag{3.3}$$

$$\beta = \sqrt{r^2 - \alpha^2} \tag{3.4}$$

We adjust α in Equation (3.4) to r - h to get β as a function of h, as illustrated in Equations (3.5) and (3.6).

$$\beta(h) = \sqrt{r^2 - (r - h)^2} \tag{3.5}$$

$$\beta(h) = \sqrt{2rh - h^2} \tag{3.6}$$

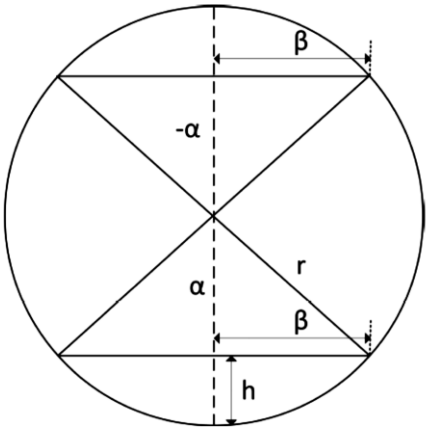

Figure 3.2: Separator-end sketch of liquid area cross section type

When the oil liquid level climbs over the separator halfway, it appears likely that issues may arise. In certain types of situations, α will have a negative value, which can't be used in calculations. Nevertheless, symmetrical considerations resolve this issue. A prof demonstrating that the computations are valid despite the negative α.

Using the equation for liquid surface width, we can calculate the cross-section type area. It is determined by integrating line segments between h = 0 and liquid level. A is the area of the liquid level cross section (h).

The area A (*h*) may also be computed by integrating the equation given below.

$$A(h) = 2.\int_0^h \sqrt{2rh - h^2}\ dh' \tag{3.7}$$

$$A(h) = 2.\int_0^h \beta(h')\ dh' \tag{3.8}$$

$$V(h) = 2l.\int_0^h \beta(h')\ dh' \tag{3.9}$$

Multiply the cross-section type area by the length L of the region that is dedicated to the liquid to get the amount of liquid that is present. Using Equation (3.9) in one's computations will allow one to compute the volume derivative.

The construction of the tank as well as its dimensions are shown in figure 3.3, which may be used to calculate the volume. To get the volume of the liquid, substitute into the following equation:

$$\frac{dAh}{dt} = \frac{d}{dt}(2l.\int_0^h \beta(h')\ dh') \tag{3.10-a}$$

The following equation may be obtained by differentiating the above equations.

$$\frac{dV}{dt} = \frac{d}{dt}(2l.\int_0^h \beta(h')\ dh') \tag{3.10-b}$$

Use partial differential to find the value of the equations 3.11 and 3.12

$$\frac{dV}{dt} = 2l.\frac{\partial}{\partial h}\left(\int_0^h \beta(h')\ dh'\right).\frac{\partial h}{\partial t} \tag{3.11}$$

$$\frac{dV}{dt} = 2l.(\beta(h) - \beta(h)).\frac{\partial h}{\partial t} \tag{3.12}$$

For slight height deviations in the center of the tank, the breadth of the liquid's surface will vary little. For modest level fluctuations, it may be assumed that the separator has smooth sides.

On the other hand, when the change is significant, we have to take into consideration the variations in width that the separator shape provides.

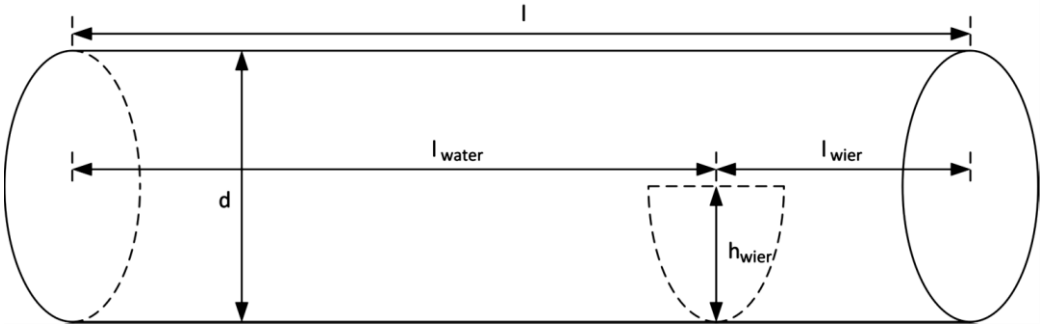

Figure 3.3: A schematic drawing of the separator tank that depicts the tank's internal Elements

3.3.1. Water Level Model

Mass balancing may be used to determine the liquid level (Egeland and Gravdahl, 2003). There is also an article by other authors on the same topic (Sayda and Taylor 2007). Calculating the rise or fall in water level requires solving the mass balance given by Equation (3.13).

Both the incoming water mass flow $w_{iw}$and the outflow water mass flow w_{ow} are analyzed. Zw denotes flashing action.

$$\frac{dm_w}{dt} = w_{i_w}(t) - w_{o_w}(t) - Z_w \tag{3.13}$$

When mass is taken into consideration, equation 3.12 may be rewritten as the following equation:

$$\frac{dV_w}{dt}\rho_w = \rho_{i_w} q_{i_w}(t) - \rho_{o_w} q_{o_w}(t) - Z_w \tag{3.14}$$

The density of water, ρ_w may be considered to remain constant, resulting in a constant volume. $\rho_w\,(t)$ is the net water volume flow $\rho_{iw}(t) - \rho_{ow}(t)$. As flashing is not included in the study, Z*w* is omitted from further computations.

$$\frac{dV_w}{dt} = q_{i_w}(t) - q_{o_w}(t) \tag{3.15}$$

The equation may be modified by adding the volume value as follows:

$$\frac{d\partial}{dt}\left(2l_w.\int_0^{h_w}\beta(h')\ dh'\right).\frac{dh_w}{dt} = q_{i_w}(t) - q_{o_w}(t) \tag{3.16}$$

On one side of the equation, write $\frac{dh_w}{dt}$:

$$\frac{dh_w}{dt} = \frac{1}{\frac{d\partial}{dt}\left(2l_w.\int_0^{h_w}\beta(h')\,dh'\right)}q_w(t) \tag{3.17}$$

Integration of the equation can be done as follows:

$$\frac{dh_w}{dt} = \frac{1}{2l_w\,.(\,\beta(h_w)-\beta(h_0))}q_w(t) \tag{3.18}$$

Equation (3.18)'s differential expression represents the change in water level. It is preferable to convert the model into the frequency domain for analytical reasons, as determined by computations from Equation (3.19).

$$\mathcal{L}\left\{\frac{dh_w}{dt}\right\} = \mathcal{L}\left\{\frac{1}{2l_w\beta_w\left(h_{w_{sp}}\right)}(q_w(t))\right\} \tag{3.19}$$

Our model is nonlinear, thus before creating a transfer function, the model must be linearized. The water level should be linearized around setpoint $h_{w_{sp}}$.

As shown by the following equations:

$$sh_w(s) = \frac{q_w(s)}{2l_w.\beta_w\left(h_{w_{sp}}\right)} \tag{3.20}$$

$$h_w(s) = \frac{q_w(s)}{2l_w.\beta_w\left(h_{w_{sp}}\right)s} \tag{3.21}$$

The nonlinear system must be linearized around different values of $\beta(h)$ before analysis can be performed. Nonlinearity inside the system may have unintended consequences.

3.3.2. Oil Level Model

We know how to develop the model for the oil level. We take into account how the water level hw and the oil level ho relate. First, the separator's available oil volume is determined.

From Figures 3.1 and 3.3. According to the equation (3.22), the quantity of oil has been divided into three sections.

The distance between water level and the top of weir is denoted by *lw*. The distance from the top to the oil surface is l, and the distance from the bottom spacer to the top of the winch behind the winch is *l-lw*. Our model prevents the oil level from falling below the weir top.

This implies that the oil, which is located in the cylinder below the weir and on the outflows side, may be thought of as having a constant volume. It is common knowledge that the water level affects the oil level.

$$V_o(h_w, h_o) = V(h_w) + V(h_o) + V_{wier} \tag{3.22}$$

By calculating the partial differential of equation 3.22, we can distinguish between the water modulus and the oil modulus, as seen in equation 3.23.

$$\frac{dV_o(h_w,h_o)}{dt} = \frac{\partial V_o}{\partial h_w} \cdot \frac{dh_w}{dt} + \frac{\partial V_o}{\partial h_o} \cdot \frac{dh_o}{dt} \tag{3.23}$$

The water modulus is v1 and the oil modulus is v2.

$$\frac{dV_o(h_w,h_o)}{dt} = \frac{\partial V_{o1}}{\partial h_w} \cdot \frac{dh_w}{dt} + \frac{\partial V_{o2}}{\partial h_o} \cdot \frac{dh_o}{dt} \tag{3.24}$$

We partitioned the oil derivatives into two portions: the size below the weir, as vo1, and the volume above the weir, as vo2. Using the 3.25 equation and equation 3.29, we can calculate each portion separately.

$$V_{o1} = 2l_w \,.\int_{h_w}^{h_{wier}} \beta(h')\ dh' \tag{3.25}$$

We calculate the difference in volume Vo1 between zero and height h by using the differential value. Equations 3.26, 3.27 and 3.28.

$$\frac{\partial V_{o1}}{\partial h_w} = 2l_w.\frac{\partial}{\partial h}\left(\int_0^h \beta(h')\ dh'\right).\frac{\partial h}{\partial t} \tag{3.26}$$

$$\frac{\partial V_{o1}}{\partial h_w} = 2l_w \,.\frac{\partial}{\partial h_w}(B(h_{wier}) - B(h_w)) \tag{3.27}$$

$$\frac{\partial V_{o1}}{\partial h_w} = 2l_w \,.(-B(h_w)) \tag{3.28}$$

Vo2 can be determined by integrating the weir height and the oil surface ho values.

$$V_{o2} = 2l \,. \int_{h_{wier}}^{h_o} \beta(h') \; dh' \tag{3.29}$$

$$\frac{\partial V_{o2}}{\partial h_w} = 2l \,. \frac{\partial}{\partial h_o} (\beta(h_o) - \beta(h_{wier})) \tag{3.30}$$

$$\frac{\partial V_{o2}}{\partial h_w} = 2l \,. \beta(h_o) \tag{3.31}$$

The method for determining mass balance, that can be found in Equation 3.32, enables one to determine the difference in oil level. "Zo" is the symbol that represents flashing.

$$\frac{dm_o}{dt} = w_{i_o}(t) - w_{o_o}(t) - Z_o \tag{3.32}$$

$$\frac{dV_o}{dt} \rho_o = \rho_{i_o} q_{i_o}(t) - \rho_{o_o} q_{o_o}(t) - Z_o \tag{3.33}$$

We will proceed with the remaining computations for volume flow on the assumption that the oil's density, ρ_o, remains unchanged.

The study does not take into account Flashing Zo, and it is not utilized in any of the subsequent computations. The quantity of oil produced in a given time period is denoted by the symbol q_o, and its value may be calculated as follows:

$$q_o = q_{i_o}(t) - q_{o_o}(t) \tag{3.34}$$

$$\frac{dV_o}{dt} = q_{i_o}(t) - q_{o_o}(t) \tag{3.35}$$

When paired with the mass balance equations, Equations 3.28 and 3.31, which describe the volume of the oil, offer the model for the change in oil level indicated by Equations 3.31.to 3.38.

$$\frac{\partial V_{o1}}{\partial h_w} \cdot \frac{dh_w}{dt} + \frac{\partial V_{o2}}{\partial h_o} \cdot \frac{dh_o}{dt} = q_{i_o}(t) - q_{o_o}(t) \tag{3.36}$$

By moving Vo1 to the opposite side of the equation, we have an expression for the value of Vo2 on its own.

$$\frac{\partial V_{o2}}{\partial h_o} \cdot \frac{dh_o}{dt} = q_{i_o}(t) - q_{o_o}(t) - \frac{\partial V_{o1}}{\partial h_w} \cdot \frac{dh_w}{dt} \tag{3.37}$$

To get the rate of change of ho, we divide both sides of the equation by the differential Vo2 as given in equation 3.38.

$$\frac{dh_o}{dt} = \frac{q_{i_o}(t) - q_{o_o}(t) - \frac{\partial V_{o1}}{\partial h_w} \cdot \frac{dh_w}{dt}}{\frac{\partial V_{o2}}{\partial h_o}} \tag{3.38}$$

$$h_o(s) = \frac{q_w(s) - (\beta(h_{w_{sp}}) \cdot k_w)}{2l(\beta h_{o_{sp}})s} \tag{3.39}$$

In order to conduct an investigation into the height of the water, we must first move the system into the frequency domain. In order to generate a transfer function, we need to linearize the system that is outlined in Equation (3.38), with the working point serving as the pivot point.

The assumption that the water level at a working area is always the same, with a magnitude of kw, is made in order to simplify the calculation. The linearized oil level model can be represented by the equation below in the time domain (3.39).

3.3.3. Gas Pressure Model

Total gas pressure inside the separator is affected by the gas's density, mass balance, and accessible volume. Although the flash exists in the mass balance calculation, it is not taken into account here despite the fact that it also relies on the temperature. We will now determine the gas pressure model. In order to do this, we must first determine how much gas is now present and what its derivative is.

It is known that a gas will occupy the rest of the separating volume from the liquid's surface to the separator's height, as shown by the equation 3.40.

$$V_g(h_o) = 2l \,.\, \int_{h_o}^{h_{2r}} \beta(h')\ dh' \tag{3.40}$$

And by eliminating the remaining sides of the equation by taking the differential of the equation along with the coefficient of ho, which allows one to do so.

$$\frac{\partial V_g}{\partial h_o} = \frac{\partial}{\partial h_o} \left(\beta(h_{2r}) - \beta(h_o)\right).2l \tag{3.41}$$

as a result of that, in order to obtain an equation in which the only variable that appears in the equation is ho:

$$\frac{\partial V_g}{\partial h_o} = -B(h_o) \cdot\ 2l \tag{3.42}$$

By considering the partial differential of the equation (3.42), we are able to get at an equation with one variable ho that changes over time, as demonstrated by the following equations:

$$\frac{dV_g}{dt} = \frac{\partial V_g}{\partial h_o} \cdot \frac{dh_o}{dt} \tag{3.43}$$

$$\frac{dV_g}{dt} = -B(h_o) \cdot 2l \cdot \frac{dh_o}{dt} \tag{3.44}$$

Equation (3.45), which contains the ideal gas law, and Equation (3.51), which contains the mass balance (3.46). If the mass balance shown in Equation is multiplied by the factor Zg, flashing can be taken into account (3.46). However, it is not applied to subsequent calculations in this instance.

$$pV_g = m_g RT \tag{3.45}$$

$$\frac{dm_g}{dt} = w_{i_g}(t) - w_{o_g}(t) - Z_g \tag{4.46}$$

A differential equation for gas density is required since the gas's density is not constant.

$$m_g = \rho_g V_g \tag{3.47}$$

The ideal gas law allows it to be replaced into the previous equation.

$$pV_g = m_g RT \tag{3.48}$$

The following equation can be obtained by subtracting the volume from both sides of the equation.

$$p = \rho_g RT \tag{3.49}$$

Then we take the pressure differential with time for the equation.

$$\frac{dp}{dt} = \frac{d\rho_g}{dt} RT \tag{3.50}$$

dt = RT = 0; hence, the pressure derivative can be found by using the equation found here (3.51)

$$\frac{d\rho_g}{dt} = \frac{1}{RT} \cdot \frac{dp}{dt} \tag{3.52}$$

The mass derivative has been calculated. In this case, we will suppose that the separator maintains a constant temperature. With Equations (3.53),(3.54), and (3.55), we have a complete model for the evolution of gas pressure (3.55). (Haugen,2009).

$$\frac{dm_g}{dt} = \frac{d\rho_g}{dt} V_g + \rho_g \frac{dV_g}{dt} \tag{3.53}$$

$$\frac{dm_g}{dt} = \frac{V_g}{RT}\frac{dp}{dt} + \rho \frac{dV_g}{dt} \tag{5.54}$$

$$\frac{dm_g}{dt} = \frac{V_g}{RT}\frac{dp}{dt} + \frac{P}{RT}\frac{dV_g}{dt} \tag{5.55}$$

It is possible to determine how much gas there is. by taking the gas on the exterior and subtracting it from the gas on the inside.

$$w_{i_g}(t) - w_{o_g}(t) = \frac{V_g}{RT}\frac{dp}{dt} + \frac{P}{RT}\frac{dV_g}{dt} \tag{3.56}$$

As a result, we are able to compute the change in pressure using the equation that is provided below.

$$\frac{dp}{dt} = RT\left(\frac{w_{i_g}(t) - w_{o_g}(t)}{V_g}\right) - p\,\frac{\frac{dV_g}{dt}}{V_g} \tag{3.57}$$

3.4. CONTROL VALVE MODEL

Control valves are actuators that restrict flow by dynamically changing the cross - sections of the valve in response to a control input. Equation (3.58) represents the model for smooth and friction coefficient flow over a constraint (Egeland and Gravdahl 2003).

$$q(z,p) = C_v f(z)\sqrt{\frac{2\Delta p}{\rho\left(1-\left(\frac{A_2}{A_1}\right)^2\right)}} \tag{3.58}$$

The altered value from the controller z affects how the valve opening A2 operates. We can simplify the flow through the valve to be represented by Equation when the size of the pipe A1 grows significantly larger than the area of the valve A2 (3.59).(Balchen.2003)

$$q_o = C_v f(z)\sqrt{\frac{2\Delta p}{\rho}} \tag{3.59}$$

$C_v f(z)\sqrt{\frac{2\Delta p}{\rho}}$ can be made equal to a constant Kv when any gas pressure comes near the set point value.

Time delays and time constants are frequently present in big valves. For this plant, the time constant for liquid valves is T = 12 seconds, as well as the dead band is specified as t = 10 seconds. It is modelled as a first-order dynamic with a time constant. It is believed that there is no friction in the pipes and valves. Equation (3.62) provides the time domain valve equation for a nonlinear valve linearized around with a working point (z_{wp}) and a setpoint (Sp) of gas pressure.

$$h_a(s) = \frac{1}{T_a s+1} e^{-\tau s} \tag{3.60}$$

$$q_o(s) = \frac{k_v f(Zwp)}{Ts+1} e^{-\tau s} \tag{3.61}$$

In order to obtain the final form of the equation,

$$h_a = \frac{q}{Ts+1} e^{-\tau s} \tag{3.62}$$

In equation (3.63), the symbol f (z) represents an example of a nonlinear term.

$$f(x) = \alpha^{x-1} \cdot 100\,. \quad \alpha = 35, \quad x = \frac{z}{100} \tag{3.64}$$

According to the design, the valve functions similarly to low pass filters but has a nonlinear gain and a time delay instead. Therefore, it is not suitable as a lowpass filter since even slight changes in the signal can tear the valve, which will result in leakage and an uncertain opening. Because of this, the valve requires a signal that contains very little noise in order to function well.

3.4.1. Model of a Water Valve

The equation for flow is through a limitation found in Equations serves as the foundation for a water valve (3.65) and (3.66). There is a constant named k_{vw} in the equation $C_v A_{vw}\sqrt{\frac{2}{\rho_w}}$. Equation provides the same Percent nonlinear characteristics for valve opening (3.67).

$$q_w = C_v f(zw)\sqrt{\frac{2}{\rho_w}(p_1 - p_2)} \tag{3.65}$$

$$q_w = k_{v_w} f(zw)\sqrt{(p_1 - p_2)} \tag{3.66}$$

$$f(z) = 35^{\frac{z}{100}-1} \tag{3.67}$$

Combining Equation (3.65), which contains the first-order time constant with time delay, with Equation, which contains the time delay, allows us to derive the equation that describes the output flow dynamics in the time domain (3.69).

Ta_w is the time constant for the water valve.

$$q_{w_o}(zw) = C_v f(zw)\sqrt{\frac{2}{\rho_w}(p_1 - p_2)} \tag{3.68}$$

$$h_{aw}(s) = \frac{1}{T_a s+1} e^{-\tau s} \tag{3.69}$$

The time constant Ta_w is explained by equation (3.70).

$$h_{aw}(s) = \frac{q_{w_o}}{T_{aw} s+1} e^{-\tau s} \tag{3.70}$$

Separator pressure will have an impact on the output flow. Changes in flow rate will be caused by significant pressure variations. Here, a modification is performed by merely taking into consideration the pressure of the separator gas. Though it is less than the gas pressure, the liquid columns do in fact produce pressure. As a result, the pressure that the liquid columns produce is disregarded.

3.4.2. Model of a Crude Oil Valve

The principle behind the oil valve is exactly similar to the principle behind the water valve (Equation 3.72). The calculation for the constant value of $C_v A_{vo}\sqrt{\frac{2}{\rho_o}}$ for the oil valve results in one number that is referred to as k_{vw} .

$$q_o = C_v f(zo)\sqrt{\frac{2}{\rho_o}(p_1 - p_2)} \tag{3.71}$$

$$q_o = k_{v_o} f(zo)\sqrt{(p_1 - p_2)} \tag{3.72}$$

Equation (3.72) and Equation (3.70) are combined, and the model is positioned around with a working point, to get Equation (3.70), which is the equation for oil flow dynamic in the time domain.

$$h_{ao}(s) = \frac{C_v f(zo)\sqrt{\frac{2}{\rho_o}(p_1 - p_2)}}{T_{ao} s+1} e^{-\tau s} \tag{3.73}$$

$$h_{ao}(s) = \frac{q_{o_o}}{T_{ao} s+1} e^{-\tau s} \tag{3.74}$$

The magnitude of the restrictions, the time constants, and the valves time delays are the three characteristics that differentiate the oil valve from the water valve. In addition, the pressure that is created by the liquid level is not taken into account for the oil valve.

3.4.3. Model of a Natural Gas Valve

The amount of gas that is released can be controlled by a variety of actuators located in various plants. It could be a valve or a combustor at this point. For this particular endeavor, we make use of a valve that possesses a first-order characteristic but does not have time delays. On the other hand, the time constant for the used valve is quite large.

The practical implications of it will also be made plain. When the valve is opened or closed, there will be a significant shift in the pressure inside the separator.

$$q_{g_o} = k_{v_g} \cdot \sqrt{(p_1 - p_2)} \tag{3.75}$$

When the flow formula in equation (3.75) and the first-order dynamic in equations are combined, the gas flow out of the valve is obtained (3.76).

$$h_a(s) = \frac{1}{T_a s+1} \tag{3.76}$$

We will approach gas pressure valves in the same way we did oil and water control valves, with the exception of the time constant.

$$h_a(s) = \frac{1}{T_a s+1} e^{-\tau s} \tag{3.77}$$

$$h_{a_g}(s) = \frac{k_{v_g} \cdot \sqrt{(p_1-p_2)}}{T_{a_g} s+1} e^{-\tau s} \tag{3.78}$$

$$h_{a_g}(s) = \frac{q_{g_o}}{T_{a_g} s+1} e^{-\tau s} \tag{3.79}$$

The gas control valve actuators are not simulated with a time delay. Although a delay might exist, it would be negligible in comparison to the time constant. If a pump had been operated, the time constant for the particular case's used valve Ta_g of one minute might have been as long as three minutes.

3.5. THE SCALABILITY OF THE SYSTEM

The system model must be scaled in order to simplify the model's analysis and broaden it. Another benefit is that the designer must make a determination on the system's needed overall quality (Skogasted and Postlethwait 2005).

The technique outlined below was suggested by (Skogasted and Postlethwait 2005) for SISO systems normalization and is also applicable to MIMO systems:

$$\hat{y} = \hat{h}\hat{u} + \widehat{h_d}\hat{d} \tag{3.80}$$

$$\hat{e} = \hat{y} - \hat{r} \tag{3.81}$$

The equations (3.80) and (3.81) describe the systems, with the dash (ˆ) standing for the real value. It is a frequent practice to scale variables in the range of 0 to 1. This would be accomplished using the approach recommended in Skogasted and Postlethwait (2005).

$$y = \frac{\hat{y}}{\hat{e}_{max}}, e = \frac{\hat{e}}{\hat{e}_{max}}, r = \frac{\hat{r}}{\hat{e}_{max}}, u = \frac{\hat{u}}{\hat{u}_{max}}\ ,\ d = \frac{\hat{d}}{\hat{d}_{max}} \tag{3.82}$$

$\hat{d}_{max}$ highest level of disturbances.

$\hat{u}_{max}$ maximum permitted inputs values.

$\hat{e}_{max}$ maximum permitted controller values.

$\hat{r}_{max}$ greatest anticipated modification in regard.

This technique is used with the separator's models, and the inputs are normalized around [0, 1]. By multiplying every normalized input by 100, the inputs may have been between [0, 100] to describe the processes value in percent.

3.6. METHOD FOR NORMALIZING MODEL

We can use actual measurement and flow in one exceptional situation. But since the control system often scales measurement, it makes reasonable to establish a normalized model on scaled measurement.

For process normalisation, the natural gas pressure and liquids levels are described by normalisation constants A and B, respectively, while the flow to the three-phase separators are described by normalisation constant C.

The normalized setpoints are referred to as y_r, while the normalized process variable is referred to as y. The equations that could be derived from Equation demonstrate the relationship between both the constants A and B and the levels of a liquid's wastewater and crude oil or the natural gas pressure. (3.83).

$$y_h = ah + b, \frac{dy_h}{dt} = a\frac{dh}{dt}, \quad \frac{dh}{dt} = \frac{\frac{dy_h}{dt}}{a}, \quad h = (y - b)\frac{1}{a} \tag{3.83}$$

3.7. FORMULA FOR FLOW

It is additionally necessary to normalize the qi and qo flows. The equation for the normalized outflows, which includes the valves flow normalisation constants Cs, is as follows (3.37). There are the equations that can be used to calculate the inflow (3.38).

$$q_o = Cf(z)\sqrt{\frac{\Delta p}{\rho}} = Cf(z)\sqrt{\frac{\Delta p_{nominal}}{\rho}}\sqrt{v_p} \tag{3.84}$$

$$q_i = C\sqrt{\frac{\Delta p_{nominal}}{\rho}}v_q \tag{3.85}$$

Maximum flows through the valves at normally pressure is shown by $C\sqrt{\frac{\Delta p_{nominal}}{\rho}}$.

The nominal pressure is *vp* = 1, and the percent variation from the pressure's differential are $vq \in [0, \square(\rightarrow)]$. The ($vq \in [0, \rightarrow]$). expression is an inflow divination.

Since $z \in [0, 1]$ are the values set by the controllers, ($f(z) \in [0, 1]$), gives the percentage of valves opening that are similar for both settings.

Equations 3.86 and 3.87, respectively, can be used to derive the normalization input flow and output flow representations (3.88).

$$q = q_i - q_o \tag{3.86}$$

$$q = C\sqrt{\frac{\Delta p_{nominal}}{\rho}}\ v_q - f(z)\sqrt{\frac{\Delta p_{nominal}}{\rho}}\sqrt{v_p} \tag{3.87}$$

$$q = C\left(v_q - f(z)\sqrt{v_p}\right) \tag{3.88}$$

3.7.1. Modeling Normalized for Water Level

The system is scaled using normalisation constant, a_w obtained in Equation (3.90) and b_w provided by Equation (3.91).

In computations, the normalized level of wastewater, denoted by equation (3.89), is calculated yh_w from the actual level of wastewater, denoted by h_w.

$$yh_w = a_w h_w + b_w \tag{3.89}$$

$$a_w = \frac{y_{w_2} - y_{w_1}}{h_{w_2} - h_{w_1}} \tag{3.90}$$

$$b_w = y_{h_w} - a_w h_{w_o} \tag{3.91}$$

Then let's return to the modelling of a wastewater level provided by the equation (3.18). One way to talk about the normalization modelling using function called cw. When several separators are crossed, either the amplitude of the functions as a whole shift or the elements take on a different relative importance. Both of these outcomes are possible.

$$\frac{dh_w}{dt} = \frac{1}{2l_w .(\beta(h_w) - \beta(h_0))}\left(q_{i_w} - q_{o_w}\right) \tag{3.92}$$

$$\frac{dy_{h_w}}{dt} = \frac{dh_w}{dt} \cdot a_w \tag{3.93}$$

$$\frac{dy_{h_w}}{dt} = \frac{C_w\left(v_{qw} - f(z_w)\sqrt{v_{pw}}\right)}{2l_w .\beta(h_w)} \cdot a_w \tag{3.94}$$

The model for normalization wastewater level is provided in equation (3.96). Calculation using Equation (3.18), which displays the equation's components:

$$\frac{dy_{h_w}}{dt} = \frac{(q_w)}{2l_w .\beta\left(\frac{y_{h_w} - b_w}{a_w}\right)} \cdot a_w \tag{3.95}$$

$$\frac{dy_{h_w}}{dt} = c_w\left(q_w, y_{h_w}\right) \tag{3.96}$$

3.7.2. Modeling Normalized for Crude Oil Levels

We must first determine the normalized constant a_o provided by Equation (3.98) and b_o provided by Equation for the levels of crude oil modelling (3.99). The normalized levels yh_o are provided by equation (3.97), which would be based on the actual crude oil levels h_o.

$$yh_o = a_o h_o + b_o \tag{3.97}$$

$$a_o = \frac{y_{o_2} - y_{o_1}}{h_{o_2} - h_{o_1}} \tag{3.98}$$

$$b_o = y_{h_o} - a_o h_{o_o} \tag{3.99}$$

The levels of crude oil modelling provided by Equation serves as the basis for the normalization crude oil levels modelling (3.38). We derive an actual value model-based normalized modelling function, *co*. Each plant has a different modelling and parameter weights. to analysis various magnitudes and weights for parameters changes.

$$\frac{dh_o}{dt} = \frac{q_{i_o}(t) - q_{o_o}(t) - \frac{\partial V_{o1}}{\partial h_w} \cdot \frac{dh_w}{dt}}{\frac{\partial V_{o2}}{\partial h_o}} \tag{3.100}$$

$$\frac{dy_{h_o}}{dt} = \frac{dh_o}{dt} \cdot a_o \tag{3.101}$$

$$\frac{dy_{h_o}}{dt} = \frac{C_o\left(v_{q_o} - f(z_o)\sqrt{v_{p_o}}\right) - \frac{\partial V_{o1}}{\partial h_w} \cdot \frac{dh_w}{dt}}{\frac{\partial V_{o2}}{\partial h_o}} \cdot a_o \tag{3.101}$$

$$\frac{dy_{h_o}}{dt} = \frac{q_o + (2l_w . \beta(h_w) \cdot \frac{dh_w}{dt}}{2l . \beta(h_o)} \cdot a_o \tag{3.102}$$

$$\frac{dy_{h_o}}{dt} = \frac{q_o + (2l_w . \beta)}{2l . \beta\left(\frac{yh_o - b_o}{a_o}\right)} \cdot a_o \left(\frac{yh_w - b_w}{a_w}\right) \cdot \frac{dy_{h_w}}{dt} \cdot \frac{1}{a_w} \tag{3.102}$$

Then can obtain the normalization crude oil levels design modelling using Equation (3.102).

$$\frac{dy_{h_o}}{dt} = c_o\left(q_o, y_{h_o}, y_{h_w}, \frac{dy_{h_w}}{dt}\right) \tag{3.103}$$

3.7.3. Modeling Normalized for Natural Gas Pressure

The normalized natural gas pressures, denoted by the symbol *ypg*, can be determined using the equation (3.104). The following derivation will show you how to obtain the normalisation constant *ag* and constant *bg*, which are given by Equation (3.105) and (3.106) respectively.

$$yp_g = a_g p_g + b_g \tag{3.104}$$

$$a_g = \frac{y_{g_2} - y_{g_1}}{p_{g_2} - p_{g_1}} \tag{3.105}$$

$$b_g = y_{p_g} - a_g p_{g_o} \tag{3.106}$$

$$\frac{dp}{dt} = RT\left(\frac{w_{i_g}(t) - w_{o_g}(t)}{V_g(h_o)}\right) - p\,\frac{\frac{dV_g}{dt}(h_o)}{V_g(h_o)} \tag{3.57}$$

Resuming equation (3.57) we seek to determine the normalisation of natural gas pressures modelling. Calculation demonstrates how to normalize the modelling in equations (3.107), (3.108) and (.) provides a function cg for the derivatives of normalized natural gas pressures.

$$\frac{dy_p}{dt} = \frac{dp}{dt} \cdot a_p \tag{3.107}$$

$$\frac{dy_p}{dt} = \left(\rho_g RT \left(\frac{C_g\left(v_{qg} - f(z_g)\sqrt{v_{pg}}\right)}{V_g\left(\frac{y_{h_O} - b_O}{a_O}\right)} \right) - p \frac{\frac{dV_g\left(\frac{y_{h_O} - b_O}{a_O}\right)}{dt}}{V_g\left(\frac{y_{h_O} - b_O}{a_O}\right)} \right) \cdot a_p \tag{3.108}$$

$$\frac{dy_p}{dt} = \left(\rho_g RT \left(\frac{C_g(q_g)}{V_g\left(\frac{y_{h_O} - b_O}{a_O}\right)} \right) - p \frac{2l \,.\beta\left(\frac{yh_O - b_O}{a_O}\right) \cdot \frac{dy_{h_O}}{dt} \frac{1}{a_O}}{V_g\left(\frac{y_{h_O} - b_O}{a_O}\right)} \right) \cdot a_p \tag{3.109}$$

The equation that defines the normalization gas pressure modelling can be found below (3.110).

$$\frac{dy_p}{dt} = c_p\left(g_g, y_{h_o}, \frac{dy_{h_O}}{dt}\right) \tag{3.110}$$

3.8. SYSTEM IMPLEMENT AND CONTROLLER

After the system has been designed and the mathematical model calculated, we can now implement the system and the controllers. We were able to construct the system by using MATLAB and Simulink in this part of research.

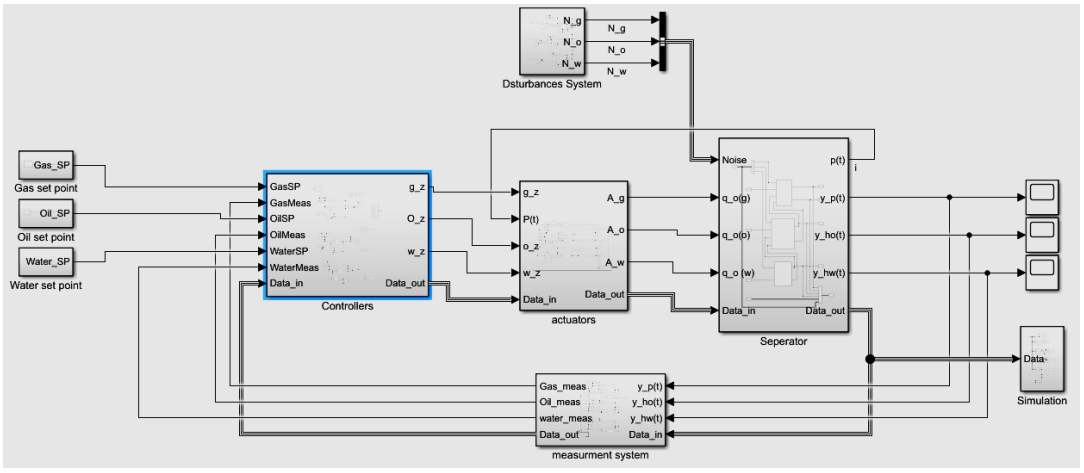

Figure 3.4. block diagram of separator simulation

As can be seen in figure 3.4, the control system is made up of a number of main components, including the separator, the controller portion, the actuator, measurement, disturbance, and subsystem simulation (data and sets point unit).

And each of them is constructed out of a variety of distinct components and elements. It is abundantly evident from examining the system that each of the main parts is associated with a number of inputs as well as a number of outputs. and that is mean multi-input and multi-output MIMO. It has a high degree of complexity.

To begin, we will explain, in general, the operation of the system in main terms of its primary components. Next, we will continue to give an in-depth explanation of each of these components so that the system can be understood.

The beginning of the input signal in the system is composed of three signals—the set points for (wastewater, crude oil, and natural gas) entering the system, where they are then received by the controller unit. in the first stage, which is the comparison of the signal that is input (the set points) with the signal that is output from the measurement instrument.

Following the comparator, error signals are outputted from it, and then they continue to the various controllers to be processed. Additionally, we will explain this section later on when we discuss the functionality of the controllers.

Actuators receive the processed signals, which are the controllers' output signals, from the controllers once the controllers have completed their processing of the signals.

actuators are either the final elements in a control system or individual control elements, and in this case, they are the control valves.

Receive in the control signals that are being transmitted by the controllers. The opening of the valves adjusts depending on the signals that are received.

Additionally, the outputs flow at the separators can be regulated by adjusting the valves openings in the system.

The flow rate inputs are the signals coming from the disturbance system. It is then transmitted into the main part of the system in order for it to complete processing together with the actuator signals.

The signals are then connected to the main part of the system, which is the separator. The separator is composed of three primary components in totality. Every one of the three signals goes through every one of these stages.

The structure is quite intricate. Some signals enter multiple parts. When we get to this part, we will explain it in detail, and then we will describe this subject in comprehensive.

carry out a complex and involved series of computations within the system. As was just indicated, we are going to talk about it later. And as a result, it produces the outputs of the separator, which are the levels in the separator for wastewater, crude oil, and natural gas respectively.

In the final step, the signal is transmitted to the measuring unit. This unit is responsible for processing the signals in accordance with the type of signal that can be transmitted to the comparator, which is a component of the controller unit.

Therefore, the signal would have ended the system's closed loop, and we would have provided a straightforward explanation of how the system as a whole is supposed to operate. .and later on, we will go through in depth what each of the components performs.

We are able to gain a simplified understanding of the workings of the system with the help of this short summary; nevertheless, we cannot rely on it to provide us with an accurate understanding of the structure and operation of that system.

As a result, we will go into detail on each of those components. Except for the controllers, which you mention at the end of this explanation; nevertheless, we will go through with them the many types of controllers that were utilized in this thesis.

3.8.1. Actuators Simulation

The control signal is transmitted to multiple components of the actuator, and these components determine the appropriate opening size for the valve based on the information they receive.

The following figure 3.5. shows the composition of the actuator unit, which represents both the actuator and the valve body and the movement between them.

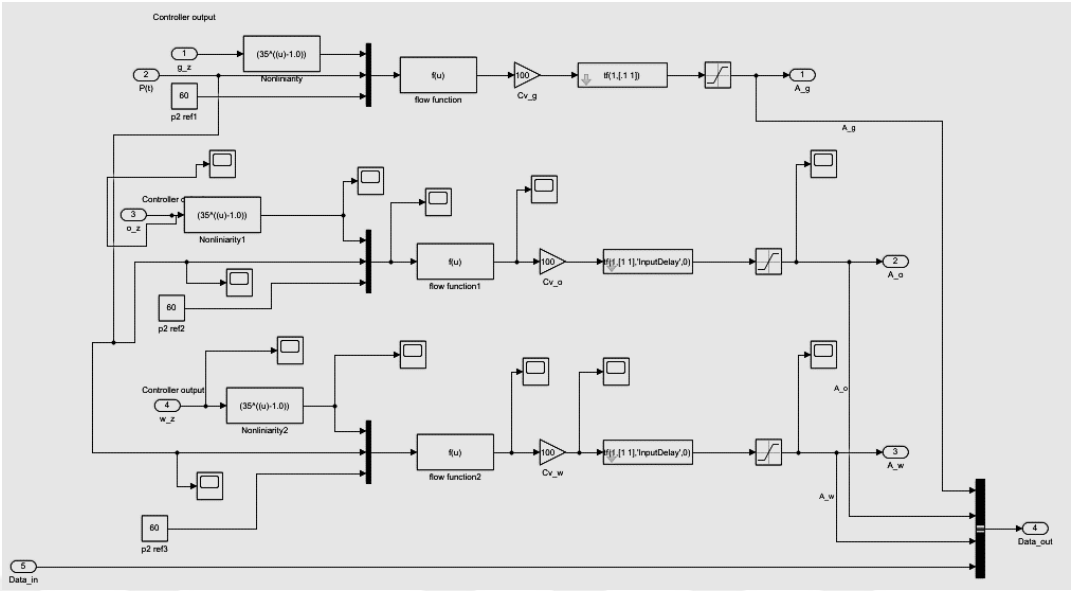

Figure 3.5. block diagram of actuators simulation

Actuator is composed of three essential parts, all of which are connected in parallel, and each of these parts represents a different component of the system: the wastewater element, the crude oil element, and the natural gas element.

For a better understanding of the components that make up each of these pieces, we can refer to the mathematical analysis model.

In the beginning, it discusses the input and output signals that are used by the actuator. Along with the synchronized time of the system, the four input signals that arrive from the controller are the controller signals for the variables gas pressure, liquid level of crude oil, and liquid level of water.

In addition, the synchronized time of the system is one of the input signals. The fifth signal, which represents the gas pressure in respect to the other signals.

In terms of the signals that are output by the actuator, they include the synchronous time of the system in addition to each of the output signals that are produced by the three valves that control the flow of water, crude oil, and natural gas.

And to further our comprehension, we'll look at one of these sections, let's say the crude oil section, because the actuators are comparable to one another. The water section and the natural gas section don't differ all that much in terms of the valves, and there is one difference where we’ll discuss after explain the crude oil actuator system.

Only the crude oil actuator is depicted in the following figure3.6; it applies to the rest of the parts, and we will explain its practical method and composition according to the equations that were carried out in the part of the article that was devoted to the systemic mathematical model that was discussed earlier.

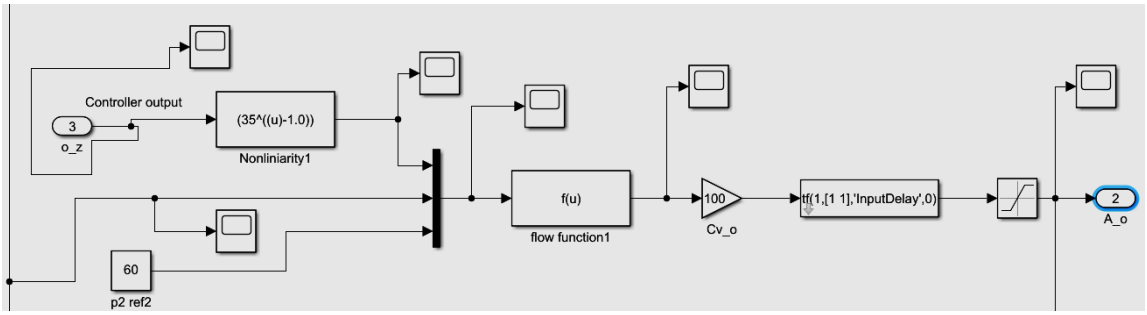

Figure 3.6. block diagram of oil actuator simulation

It is a representation of the equations 3.67, 3.71, 3.74 next: The first part is linearization, represented by the equation 3.67.

$$f(z) = 35^{\frac{z}{100}-1} \tag{3.67}$$

Flow function represented by the equation 3.71.

$$q_o = C_v f(zo)\sqrt{\frac{2}{\rho_o}(p_1 - p_2)} \tag{3.71}$$

Equation for oil flow dynamic in the time domain represented by the equation 3.74.

$$h_{ao}(s) = \frac{q_{o_o}}{T_{ao}s+1} e^{-\tau s} \tag{3.74}$$

This probably applies for the water portion in its entirety; however, the gas portion requires a little modification in the form of the substitution of equation 3.79 for equation 3.74.

$$h_{a_g}(s) = \frac{q_{g_o}}{T_{a_g}s+1} e^{-\tau s} \tag{3.79}$$

Taking into account, of course, the disparity in valve diameter between the three cases.

3.8.2. Disturbance Simulation

There are several factors that constitute the disturbance, but the three most important components are those that represent the flow of inputs into the system. The flow of inputs into the system is changeable, as are the types of inputs and the rate at which they are changed.

As can be seen in the figure 3.7. that is presented below

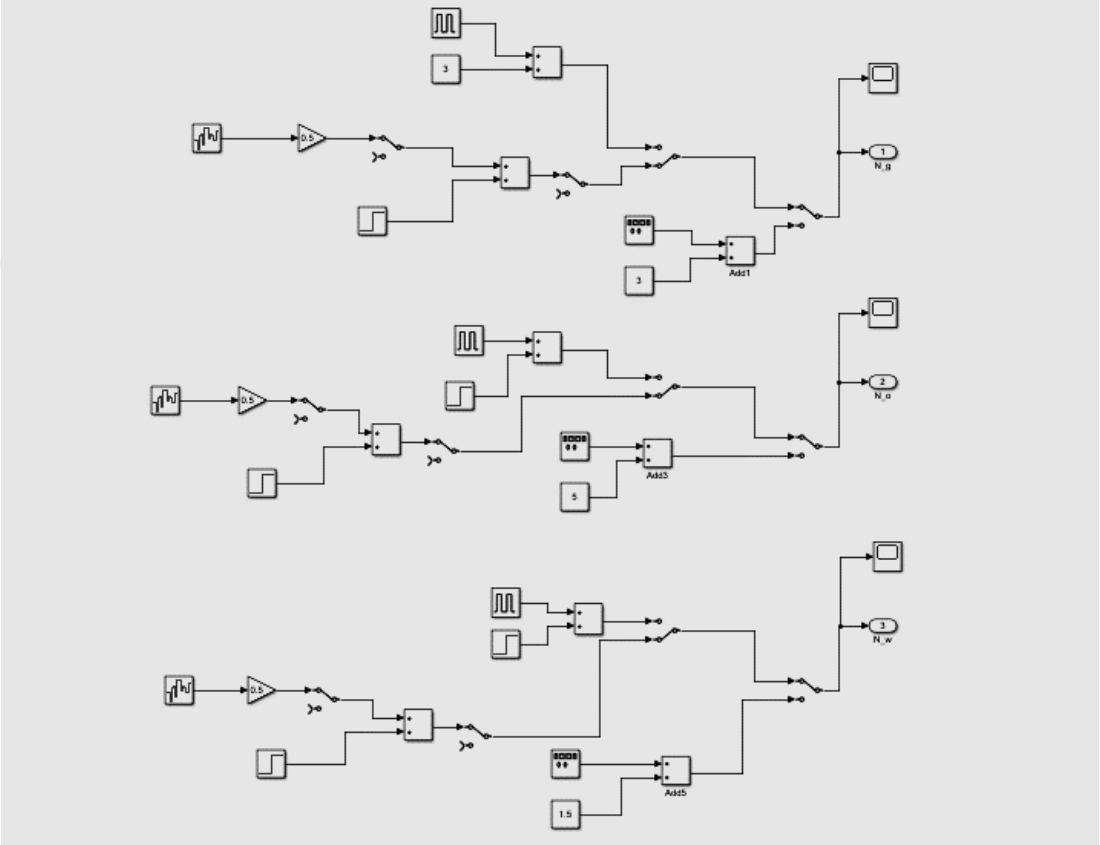

Figure 3.7. block diagram of disturbance simulation

It is made up of three different sections: one for water, one for crude oil, and one for natural gas. The values of each section can be changed by adjusting the amount of noise level.

Additionally, it is possible to change the type of noise to one of three different types, which will allow us to carry out a variety of experiments utilizing the system.

3.8.3. Separator Simulation

Separator is the main and most important part of the system.

It is a MIMO system, which stands for multi-input and multi-output. It has seven inputs, three of which are for the flow rate values input. The other inputs are for outputs values of flow rate for control valves.

The separator has three inputs: the input value for each of the natural agas, crude oil, and wastewater; and the synchronous time for the system; and the outputs. Additionally, the output is connected to the separator.

Gas and those other outputs have the same values as a function of time, and the seventh output is a contribution to synchronization of the system. and there are internal lines that connect the system to each other due to the fact that the system is MIMO.

Figure 3.8 illustrates the separator system's internal structure.

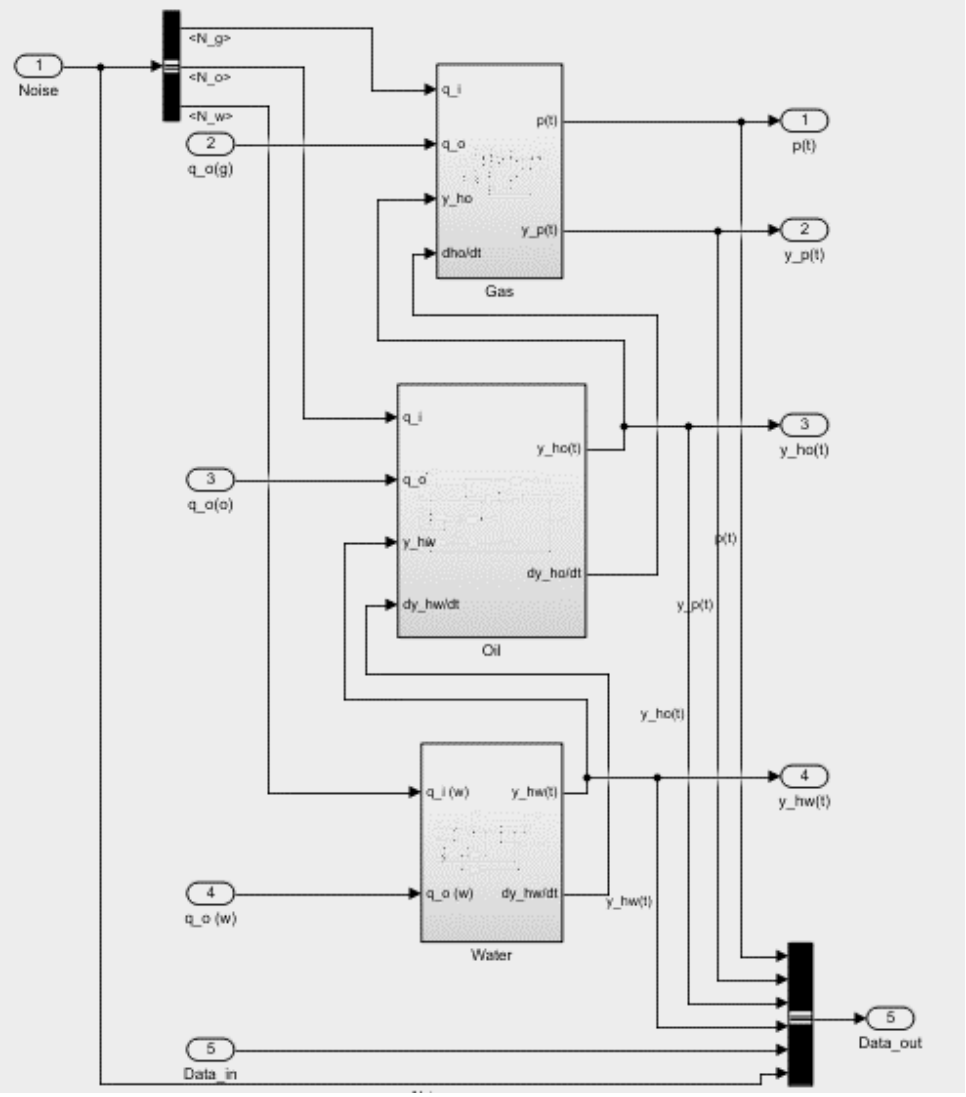

Figure 3.8. block diagram of separator simulation

3.8.3.1. Water Section of Separator Simulink

The separator can be divided into three different components: the water section, the oil section, and the gas section. As is common, we begin started with the water section since we begin our analysis from the lowest position in the separator and continue our analysis up to the highest point.

There are two entrances in the section that is responsible for separating the water; these are the locations of the water input (Q_{in}) and the water output (Q_{out}). Regarding the two outputs, they consist of the water level in the separator as well as the water level in the separator that is synchronized with the time in the function of time.

The internal structure of the separator system is shown in figure 3.9, particularly the water section.

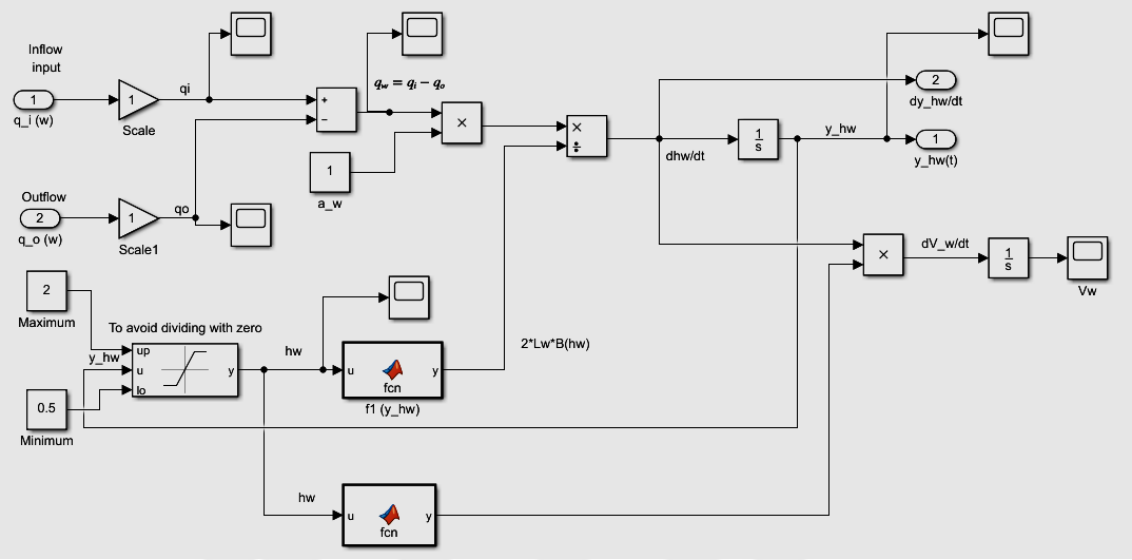

Figure 3.9. block diagram of water section of separator simulation

Within the mathematical model that we had previously developed, the mathematical equations that Simulink represents are denoted by the following equations 3.15 and 3.21:

$$\frac{dV_w}{dt} = q_{i_w}(t) - q_{o_w}(t) \tag{3.15}$$

$$h_w(s) = \frac{q_w(s)}{2l_w.\beta_w\left(h_{w_{sp}}\right)s} \tag{3.21}$$

3.8.3.2. Oil Section of Separator Simulink

These are the regions of the oil input (Q in) and the oil output (Q out), as well as the other two water levels in the separator and the water level in the separator that is synchronized with time. The section that is accountable for separating the oil has a total of four entrances. Both the oil level in the separator and the oil level in the separator that is synchronized with the time in the function of time are included in the two outputs. The oil level in the separator is one of the outputs.

Figure 3.10 illustrates the internal construction of the separator system, focusing in particular on the oil section of the system.

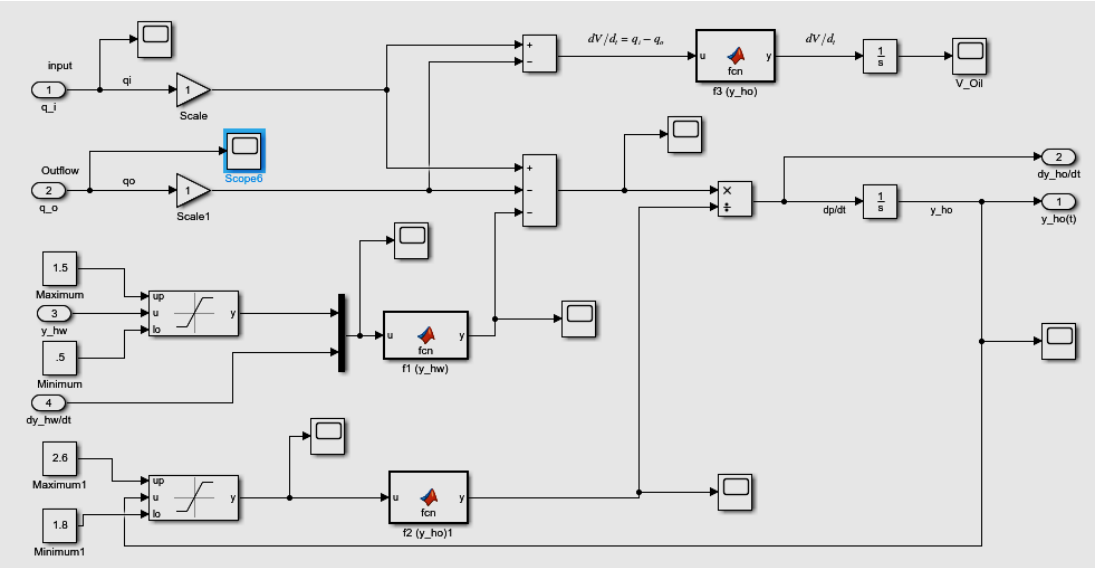

Figure 3.10. block diagram of oil section of separator simulation

The mathematical equations that Simulink represents within the mathematical model that we previously created are indicated by the following equations 3.34 and 3.39:

$$q_o = q_{i_0}(t) - q_{o_o}(t) \tag{3.34}$$

$$h_o(s) = \frac{q_w(s) - (\beta(h_{w_{sp}}) \cdot k_w)}{2l(\beta h_{o_{sp}})s} \tag{3.39}$$

3.8.3.3. Gas Section of Separator Simulink

There are four different inputs for the signal that comes in for the gas part. Similar to the situation with the crude oil section, we need to know the level of the liquid that is located before it. This is because knowing the level of the liquid that is located before it establishes the beginning point of the liquid level or the region that the gas occupies in.

Because of this, it is necessary for us to be aware of the level of the crude oil separator as well as the quantity of crude oil that is flowing out of the separation. This gives us with the value of the gas volume at this exact moment in time.

There are four entrances in the section that is responsible for separating the gas; these are the locations of the gas input (Q in) and the gas output (Q out) and anther two oil level in the separator as well as the oil level in the separator that is synchronized with time.

Regarding the two outputs, they consist of the gas pressure in the separator as well as the gas pressure in the separator that is synchronized with the time in the function of time.

In spite of the fact that the number of entries and exits in the gas section and the crude oil section are comparable to one another, the gas section is more difficult to calculate in terms of its complexity.

The internal structure of the separator system is depicted in Figure 3.11, with a particular emphasis focused on the system's gas portion as the main point of focus.

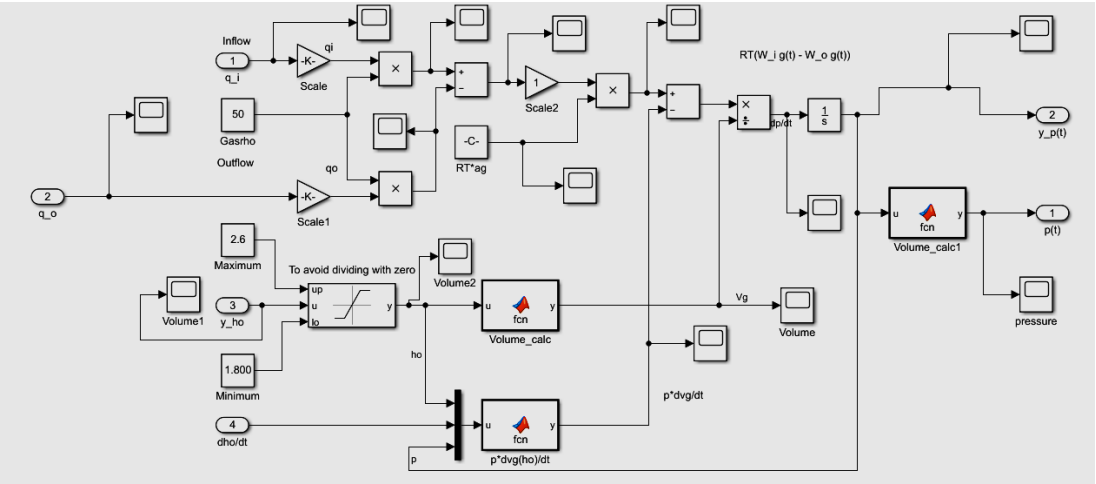

Figure 3.11. block diagram of gas section of separator simulation

The mathematical equations that Simulink depicts are denoted by the following equations 3.44, 3.45, 3.56, and 3.57 and can be found within the mathematical model that we had previously developed:

The value of gas that varies with time is found on the first side of Simulink, which is determined using equation 3.56 and the general law of gases, which is in equation 3.45.

$$pV_g = m_g RT \tag{3.45}$$

$$w_{i_g}(t) - w_{o_g}(t) = \frac{V_g}{RT}\frac{dp}{dt} + \frac{P}{RT}\frac{dV_g}{dt} \tag{3.56}$$

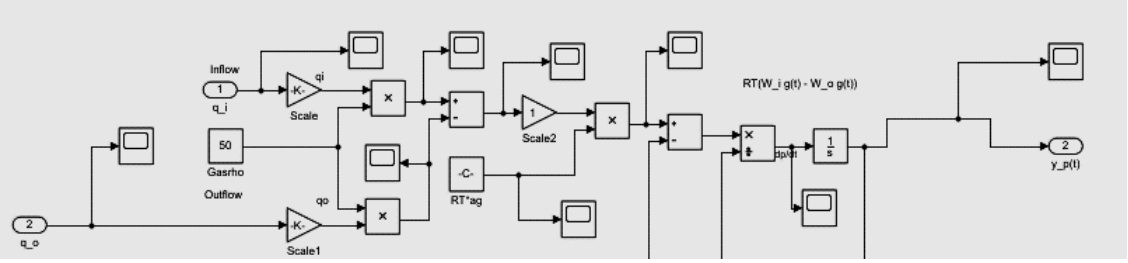

Figure 3.12: Block diagram of the gas section for calculating equation 3.56

Using Equation 3.44, it is possible to calculate the volume occupied by the gas as well as subtract the total separating volume from the volume occupied by water and crude oil, given the level of crude oil in the separation.

$$\frac{dV_g}{dt} = -B(h_o) \cdot 2l \cdot \frac{dh_o}{dt} \tag{3.44}$$

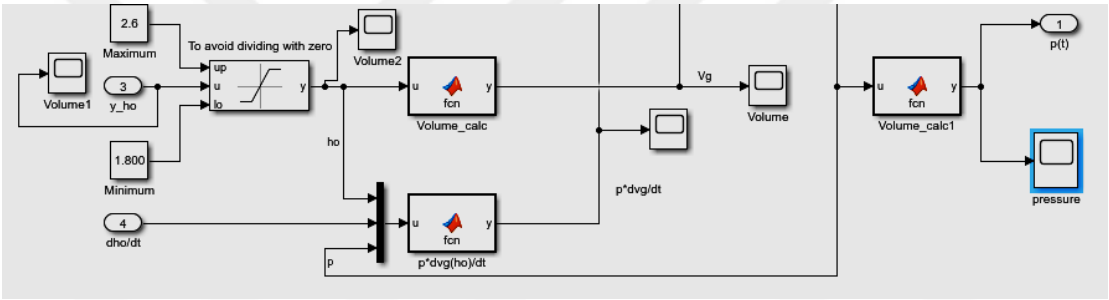

Figure 3.13: Block diagram of the gas section for calculating equation 3.44

We are able to compute the gas pressure that varies with time as well as the pressure of natural gas by applying the equations that were recently presented. This can be achieved by using the equation below:

$$\frac{dp}{dt} = RT\left(\frac{w_{i_g}(t) - w_{o_g}(t)}{V_g}\right) - p\,\frac{\frac{dV_g}{dt}}{V_g} \tag{3.57}$$

3.8.4. Simulation Data Recorder

All the information explaining the system's variables, controller signals, input signals, and output signals is read and recorded in this part. The installation of this portion is shown in the following figure 3.14 In this section, it helps us in recording and analyzing all system-related information.

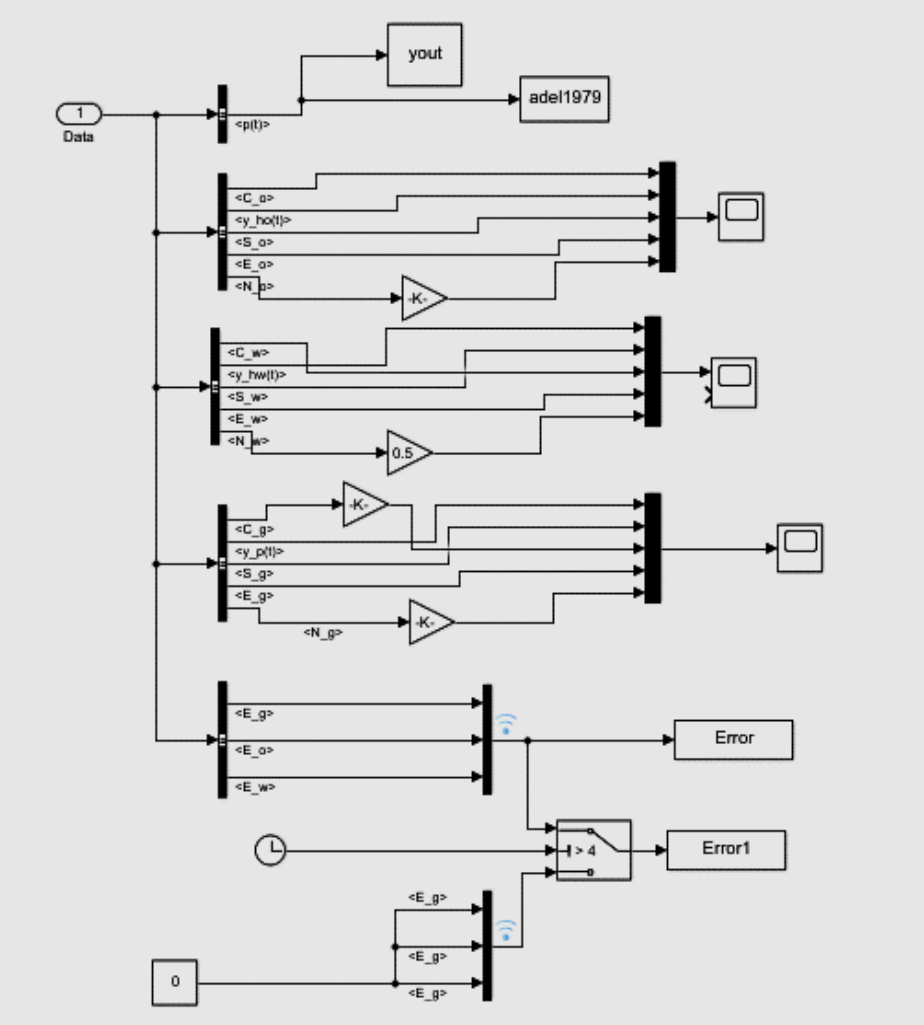

Figure 3.14. block diagram of data simulation subsection

3.8.5. Measurement Section Simulation

In this portion, the variables that come from the separator are measured. These variables include gas pressure, the level of water in the separator, and the level of crude oil in the separator.

The measurement unit measures the variables and also changes the signal from a physical signal, which represents the variables such as pressure and liquid level, to an electrical signal that the controller can deal with. This is another function of the measurement unit. The signal that comes out of it is called the feedback.

In addition to the system synchronization signal, it has four entrances and four exits. The entrances are the gas pressure, the water level, and the crude oil level in the separator.

As for the outputs, they are in the following order: the gas output signal, the water level signal, and the crude oil level signal after processing to meet controller specifications. as well as the system's synchronization signal.

Figure 3.15 below depicts the installation of the measuring portion.

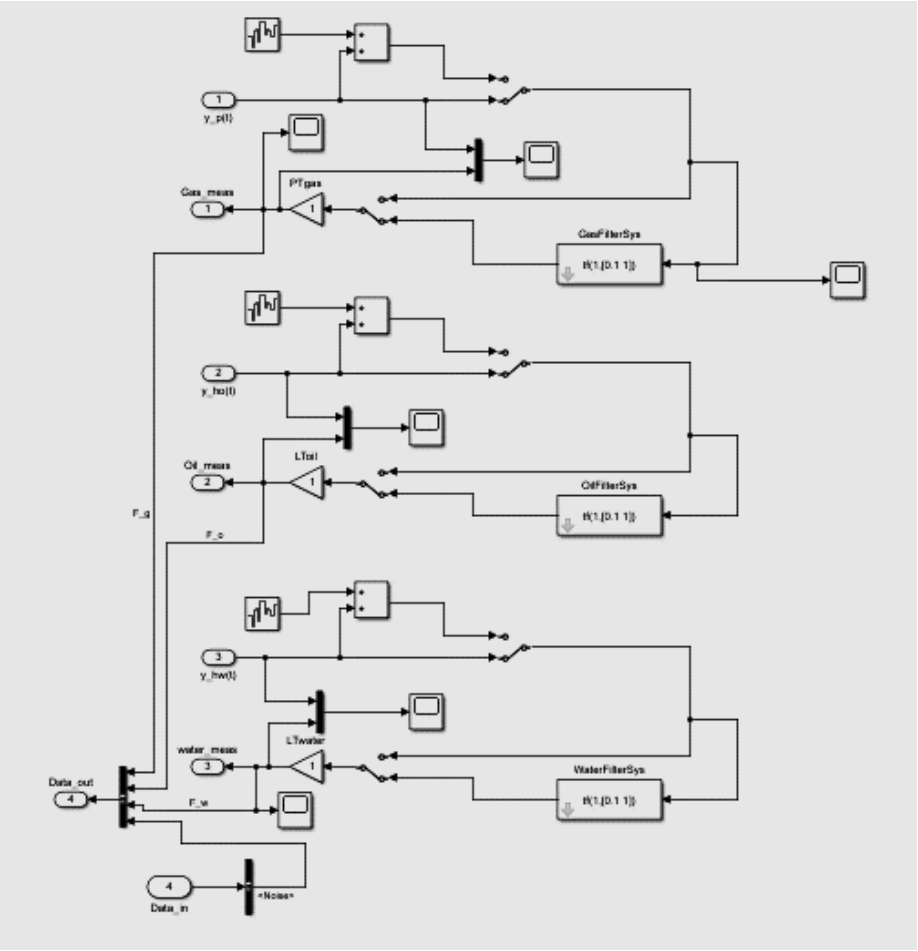

Figure 3.16. block diagram of measurement section simulation

3.8.6. Control Section Simulation

Seven inputs are represented in the controller block diagram; three of these inputs are set points, while the remaining three inputs come from the measurement unit. In addition to the synchronous one for the system, they represent the gas pressure, the water level, and the crude oil level. Regarding the system's outputs, there are four signals, three of which reflect the values of the control signals for the actuators. These values are represented by the outputs of the system. There are three that act as control valves. Gas, water, and oil are the three changes that result in the system producing its outputs, and the system itself flows from these three changes.

The object of the fourth signal, as you can see clearly represented in figure 3.17 below, is to synchronize the system.

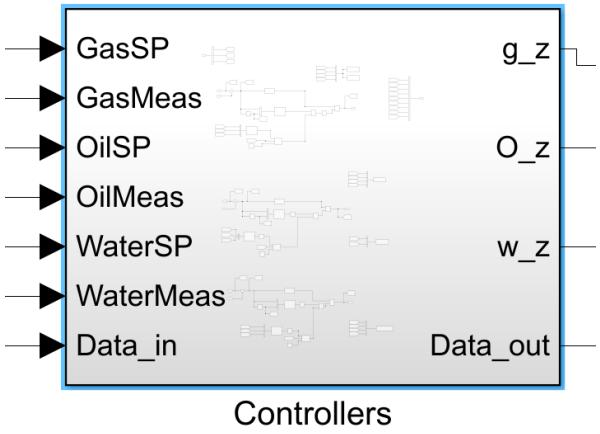

Figure 3.17. block diagram of controller section simulation

Regarding the inside, it is made up of three controls, one for each of the three different kinds of variables, which are gas, water, and crude oil, respectively. PID controllers, fuzzy logic controllers, and ANFIS controllers are the types that fall into this category.

On the interior, there are three controllers one for gas, one for water, and one for crude oil that each handle a different type of variable. PID controllers, fuzzy logic controllers, and ANFIS controllers are examples of these types.

It is important to note that the controllers are not connected to one another in order to avoid interfering with each other's act. This implies that each controller will only work on one variable without being disturbed by the status of another variable, which increases the stability of the system.

3.8.6.1. Water Control Simulation

based on Figure 3.19. Two inputs and one output are included in the water level control of the separator. Set point and the water level in the separator are the two inputs. They enter the comparator, where an error signal is generated. There is an option between three controllers when they enter the control: PID, fuzzy logic, and ANFIS.

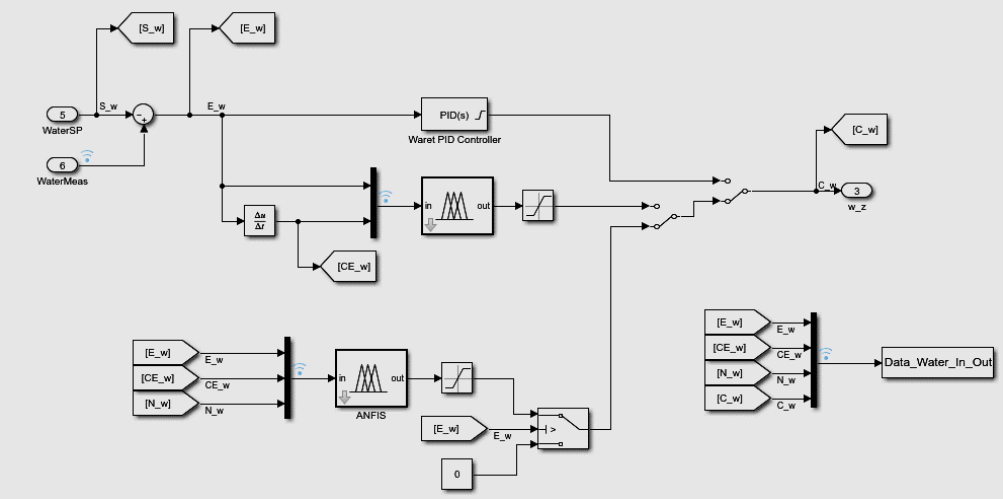

Figure 3.17. block diagram of water controller simulation

3.8.6.2. Oil Control Simulation

Figure 3.20-based. The separator's oil level is controlled by two inputs and a single output. Two such inputs are the separator's set point and oil level. They go through the comparator, which then produces an error signal. The user can select from PID, fuzzy logic, or ANFIS controllers to keep system stable**.**

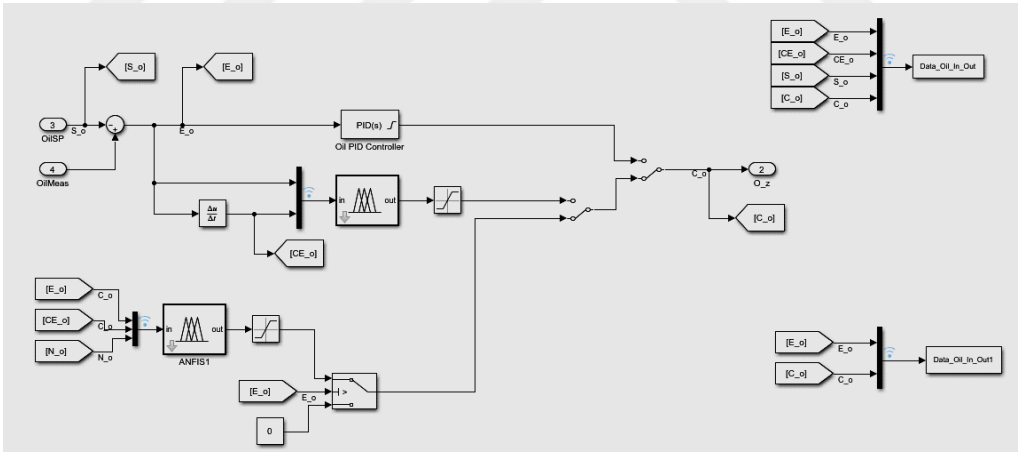

Figure 3.17. block diagram of water controller simulation

3.8.6.3. Gas Control Simulation

figure 3.20 on which to build. Two inputs and one output are used to regulate the gas pressure that is produced by the separator. The set point of the separator and the gas pressure are typical of such inputs. They are processed by the comparator, which results in the generation of an error signal. The user has the option of choosing between PID, fuzzy logic, and ANFIS controllers in order to maintain the system's stability.

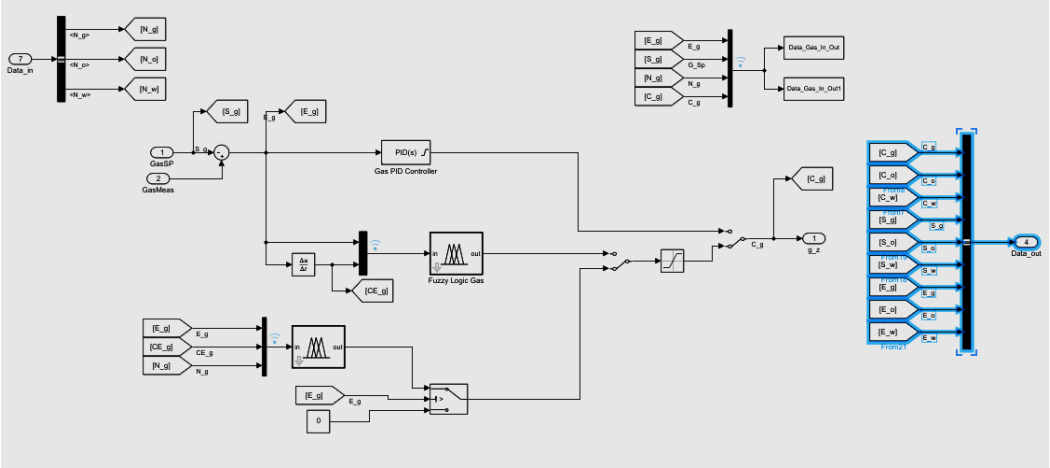

Figure 3.17. block diagram of water controller simulation

3.9. CONTROLLER DESIGN

3.9.1. PID Controller

The PID controller is the most popular and one of the most significant controllers used in control systems. because it has a wide range of qualities and high reliability. It is very simple to understand and implement**.**

The following is a mathematical model of PID control:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)\,dt \tag{3.104}$$

Kp, which is frequently the main factor in a control loop, greatly reduces the total error.

Ki decreases a system's overall error rate. Even a minor error added together over time generates a drive signal strong enough to steer the system in the direction of a smaller fault. When the output changes quickly, the kd term cancels out the Kp and Ki terms. This minimizes noise and overshoot. The final error is unaffected.

The controller PID function can be performed on the error, and the controller then applies the total of those functions to the operation. Even without high knowledge of control theory, we are able to construct a PID controller that demonstrates good performance in most practical settings. The built-in PID control was utilized in a manner consistent with its specifications. This particular type of PID is acceptable.

4. RESULTS

This research is predicated on finding a solution to the issue of fluctuating gas pressure; consequently, the results will be centered on the problem and its solution, as well as which of the controllers had better results in solving the configuration, and which specifications proved to be the most effective in overcoming the issue of fluctuating gas pressure. As a consequence, the findings were classified based on the magnitude of the pressure fluctuation change as well as the type of controller that was used.

The results of the PID controller for the three variables of the natural gas system, crude oil, and water in terms of response speed, reaching a state of stability, the shape of the controller signal, and the response to a sudden change in the input signal are as follows: Take into consideration, as well, the impact that the instability of one variable has on the other. in addition to evaluating the general performance of the controller. When it comes to the following cases:

1- zero noise

2- 25 % noise (medium noise)

3- 50% noise (high noise)

The results of the fuzzy logic controller in terms of response speed, achieving stability, the shape of the controller signal, and the response to a rapid change in the input signal for the natural gas system, crude oil, and water variables. Note also the impact of one variable's instability on the other. and evaluate the overall performance of the controller. In the following situations:

1- zero noise

2- 25 % noise (medium noise)

3- 50% noise (high noise)

The results of the ANFIS controller in terms of response speed, reaching a state of stability, the shape of the controller signal, and the response to a sudden change in the input signal for the three variables of the natural gas system, crude oil, and water Also note the influence of the instability of one variable on the other. and evaluate the performance of the controller in general. In the following cases:

1- zero noise

2- 25 % noise (medium noise)

3- 50% noise (high noise)

Finally, we evaluate the effectiveness of the three control tools by comparing their performance under the specified conditions, as well as comparing the percentage of error in each variable alone in all the controllers and identifying all their characteristics and advantages.

4.1. PID RESULTS

The results were dependent on the fact that the parameters of the PID controller were not adjusted in any way in order to be more accurate descriptions of the system's real workings in the reality. That is, the best for all cases, even if it is not the greatest possible option for each case individually.

We will use the comparison between the signal from the control unit and the signal from the valve if there is a significant change in the output of the system. This allows us to have a clearer understanding of how the system is supposed to function.

In a situation with zero distortion, the performance of the PID controller is, in general, acceptable. Even though it's a complex process, it does its work very efficiently. All signals are acceptable. We can have a long discussion about each variable in solitude.

4.1.1. PID Controller with Zero Noise (Gas Section)

It is clear from Figure 4.1 that the output of the system is steady, and that the control signal is both functioning properly and remaining stable throughout the process. It was subjected to a slight vibration, which caused distortion at the signal output of the system as well as the control signal. This distortion began when the crude oil started to vibrate, which caused a change in the

oil level and consequently the volume of the remaining gas, which in turn caused a change in the pressure.

There is also a steady-state error, although it is well within the acceptable range of variation. The control signal and the output signal of the system with respect to the natural gas of the PID controller are shown below in figure 4.1 when there is zero distortion in the system.

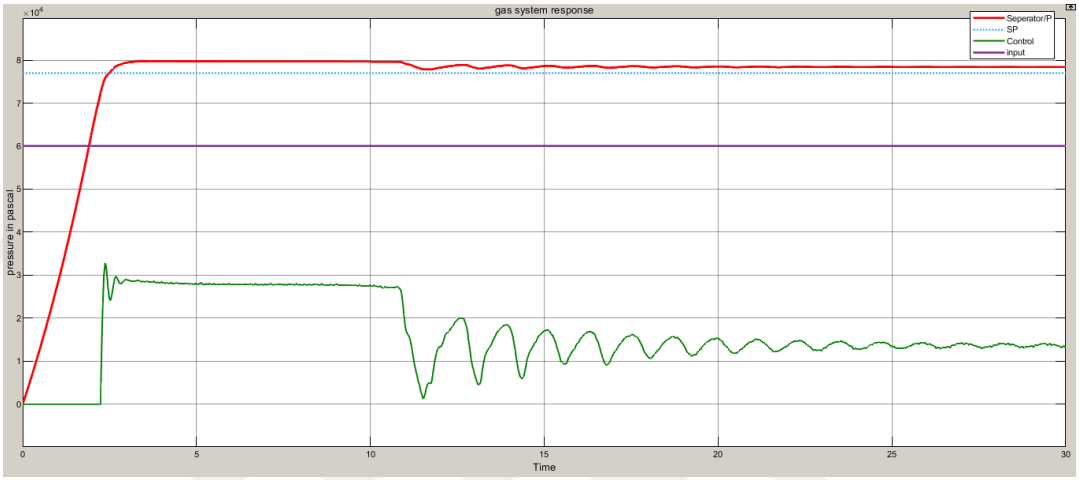

Figure 4.1 PID controller for gas with zero noise

4.1.2. PID Controller with Zero Noise (Oil Section)

Although there is a fluctuation in the signal that is output by the system as well as the signal that is output by the controller, both signals are acceptable. This is because the fluctuation that we have chosen to correspond to all cases is a small fluctuation that can be suppressed in a short amount of time. Although there is a fluctuation in the signal that is output by the system, there is also a fluctuation in the signal that is output by the controller.

There is also the steady-state error, but it is well within the range of variation that is permitted and therefore is not a cause for concern. When there is no distortion in the system, figure 4.2 shows both the control signal and the output signal of the system with regard to the oil of the PID controller. This is the case when there is "zero distortion" in the system.

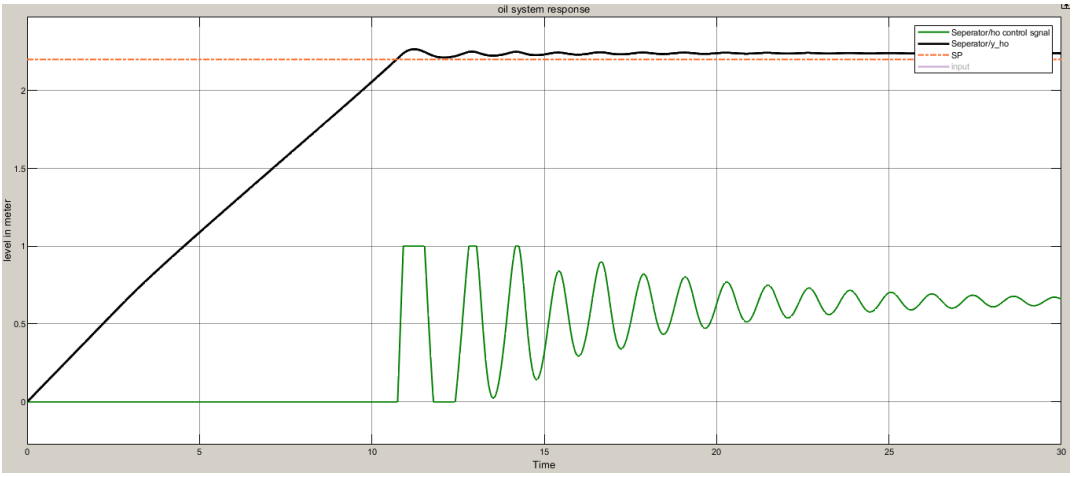

Figure 4.2 PID controller for oil with zero noise

4.1.3. PID Controller with Zero Noise (Water Section)

The system's signal and the controller's signal are both slightly variable, but they are still within acceptable ranges. The reason for this is that the fluctuation we have selected to represent all possible ones is a little one that can be dampened in a relatively short period of time. Even if the system's output signal varies, the controller's output signal varies as well.

Even though there is the steady-state error, it is within acceptable bounds and hence not an alarming sign.

Figure 4.3 depicts the PID controller's control signal and the system's output signal with respect to water when no distortion is present in the system. This is true if the system has "zero distortion."

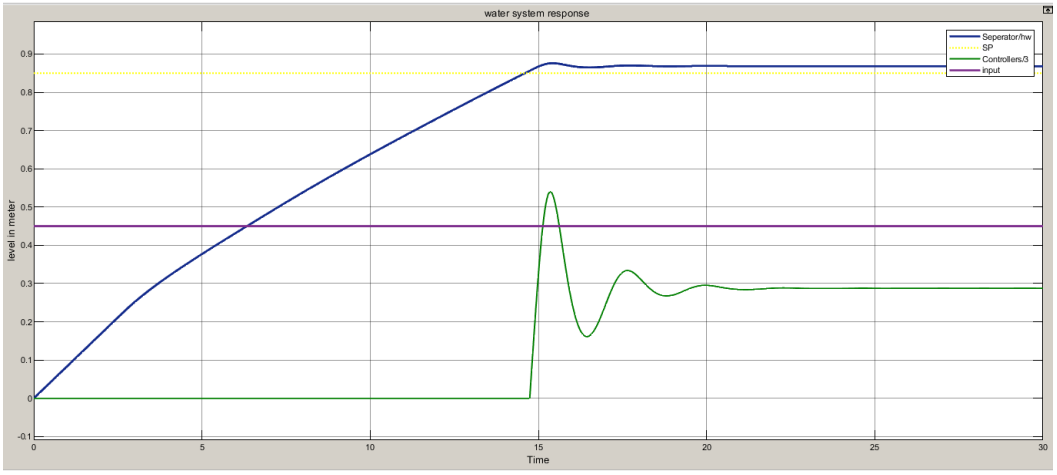

Figure 4.3 PID controller for water with zero noise

4.1.4. PID Controller with 25% Noise (Gas Section)

Figure 4.4 shows that the system's output is stable and that the control signal is operating appropriately and maintaining a stable output. Outcome is more than zero noise. It was subjected to a little vibration, which distorted both the signal output and control signal of the system. This distortion occurred when the crude oil began to vibrate, which led to a change in the oil level and, as a result, the volume of the residual gas, which led to a change in the pressure.

There is also a steady-state error, but it is well within the acceptable range of variation.

Figure 4.4 shows the control signal and output signal of the system with respect to the natural gas of the PID controller when the system is 25% noise.

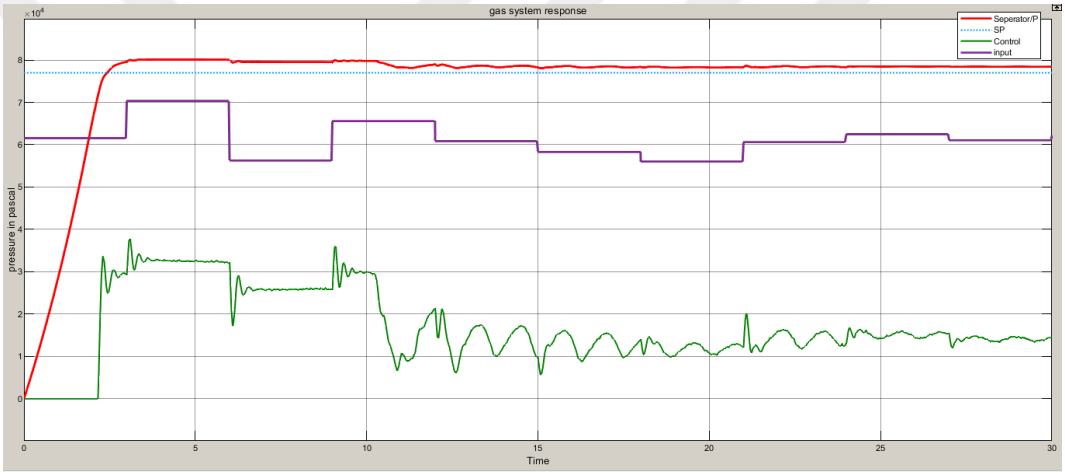

Figure 4.4 PID controller for gas with 25% noise

4.1.5. PID Controller with 25% Noise (Oil Section)

Both the system's signal and the controller's signal are slightly varied, but within acceptable parameters. This is due to the fact that the fluctuation we have chosen to represent all conceivable ones is a small one that can be mitigated in a very short amount of time. Even if the system output signal varies, so does the controller output signal.

Even though there is steady-state inaccuracy, it is within permissible limits and therefore not a cause for concern. Figure 4.5 displays the control signal of the PID controller and the output signal of the system with regard to oil when no distortion is present in the system. True if the system shows 25% noise.

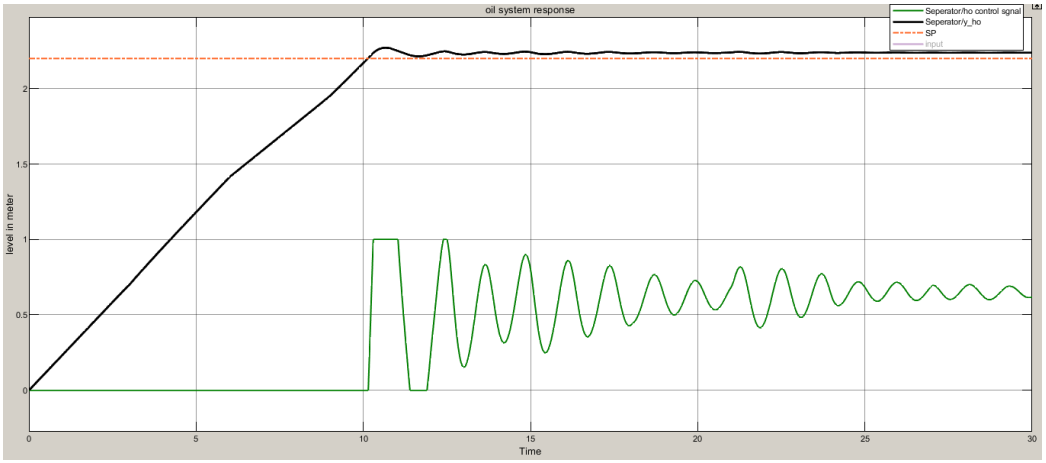

Figure 4.5 PID controller for oil with 25% noise

4.1.6. PID Controller with 25% Noise (Water Section)

Despite the fact that there is a fluctuation of 25percentage points in the input signal, the controller signal and the output signal are both steady in this case, which is a result that is considered to be satisfactory.

Figure 4.6 shows the control signal of the PID controller and the output signal of the system in relation to water when no system error is present. True if the system's noise level is 25%.

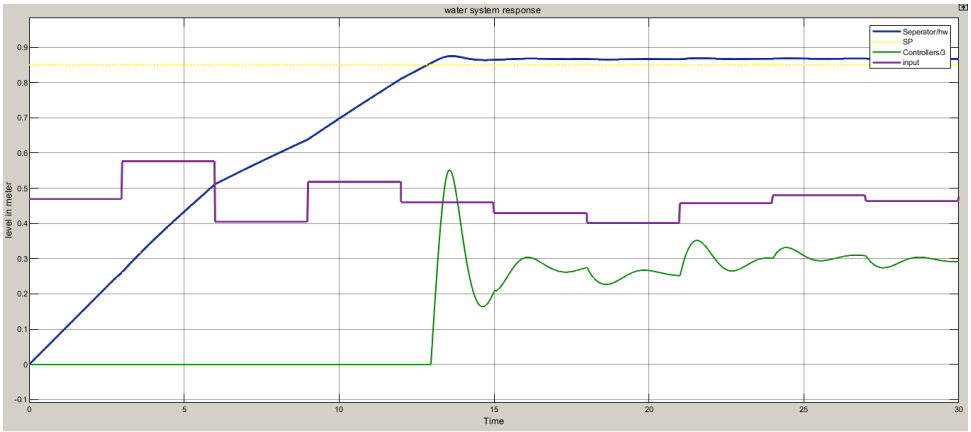

Figure 4.6 PID controller for water with 25% noise

4.1.7. PID Controller with 50% Noise (Gas Section)

In this case, the signal that is sent out by the system is critically steady, but the signal that is sent out by the controller is unstable and has a significant amount of fluctuation. This is due to the fact that the input is changeable by a ratio of fifty percent.

The control signal and output signal of the system with respect to the natural gas of the PID controller are displayed in Figure 4.7. This is the case when the system is 50% noisy.

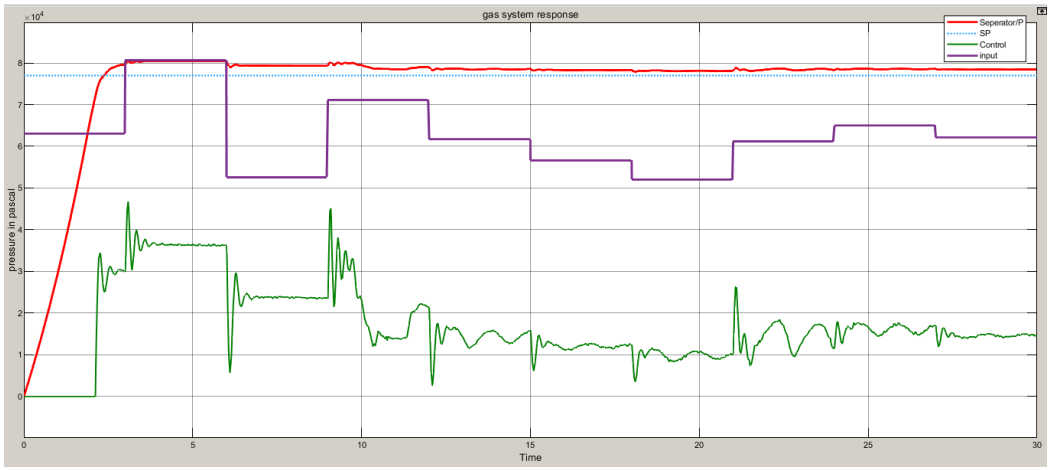

Figure 4.7 PID controller for gas with 50% noise

4.1.8. PID Controller with 50% Noise (Oil Section)

The condition of the oil is identical to the condition of the gas, and in this instance, the output signal of the system is critical stable. On the other hand, the signal of the controller is not stable and has a significant amount of fluctuation. This is due to the fact that the input is variable by a variable of 50 percent.

Figure 4.8 shows the system's control signal and output signal in relation to the crude oil used by the PID controller. When the system is 50% noisy, this is the situation.

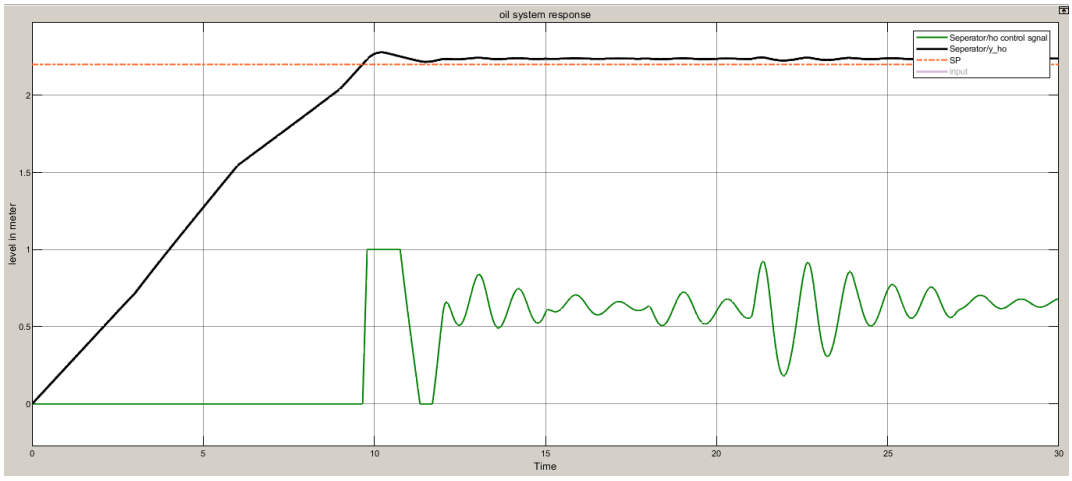

Figure 4.8 PID controller for oil with 50% noise

4.1.9. PID Controller with 50% Noise (Water Section)

In the case of water, there is some level of stability, in contrast to the cases of oil and gas. And there is an acceptable fluctuation in the control signal.

When there is a distortion of fifty percent in the system, both the control signal of the PID controller and the output signal of the system are shown in Figure 4.9 with respect to water. If the system is "50% noisy," then this is indeed the case.

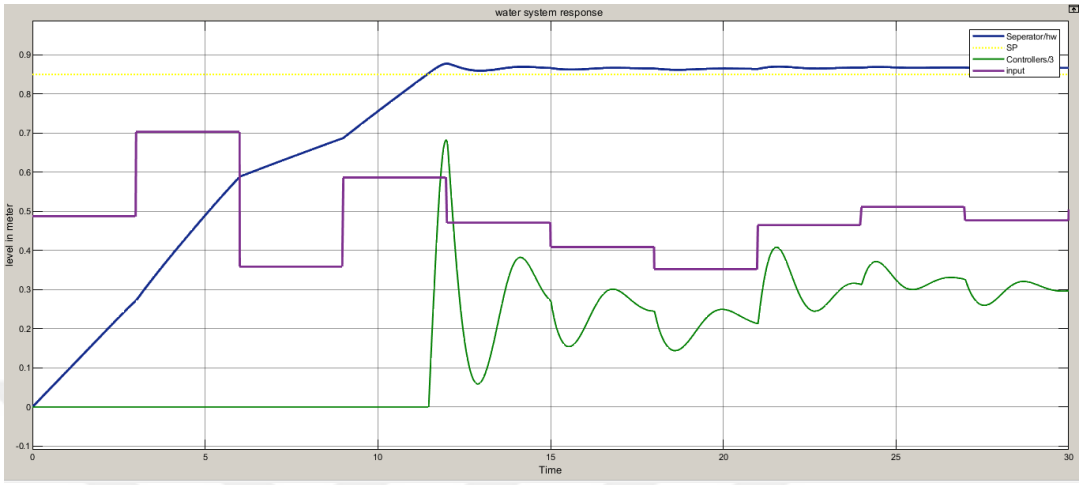

Figure 4.9 PID controller for water with 50% noise

4.2. FUZZY LOGIC RESULTS

4.2.1. Fuzzy Logic Controller with Zero Noise (Gas Section)

fuzzy logic controller is faster and more stable than pid controller. In this case specifically, both the signal at the output of the system and the signal at the controller are totally steady.

The control signal and the output signal of the system with respect to the natural gas of the fuzzy logic controller are shown below in figure 4.10 when there is zero noise in the system.

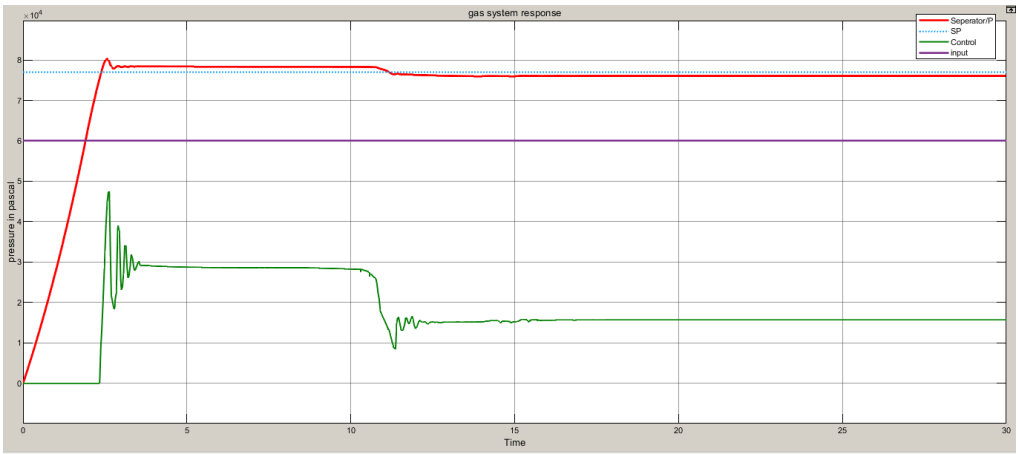

Figure 4.10 fuzzy logic controller for gas with zero noise

4.2.2. Fuzzy Logic Controller with Zero Noise (Oil Section)

A PID controller is slower and less stable than its counterpart, the fuzzy logic controller. In this specific situation, the signal that is obtained at the controller as well as the signal that is obtained at the output of the system are both completely stable.

When there is no noise in the system, both the control signal and the output signal of the system in relation to the crude oil are displayed in figure 4.11 following. This is the case when the fuzzy logic controller is fully functional.

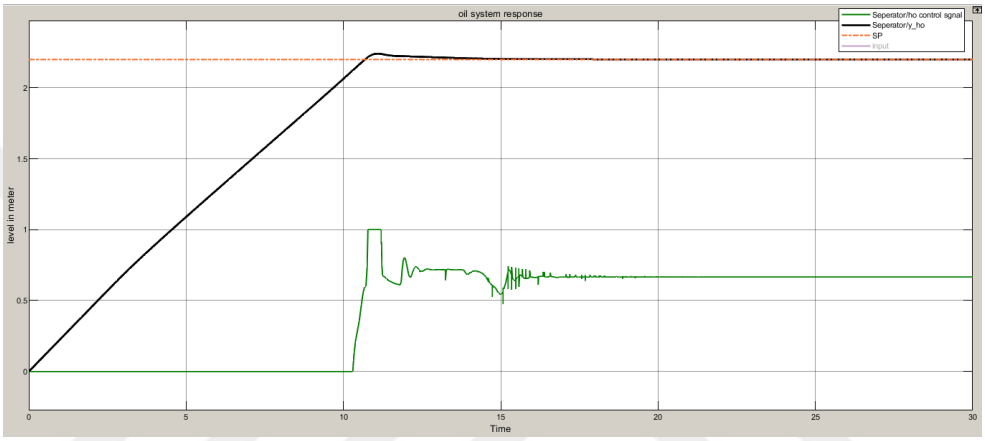

Figure 4.11 fuzzy logic controller for oil with zero noise

4.2.3. Fuzzy Logic Controller with Zero Noise (Water Section)

Both the control signal and the system signal are totally stable. This is because the controller's fuzzy logic can dampen oscillations that can be reduced within a reasonable period of time. No steady-state error happens.

When there is no system distortion, Figure 4.12 depicts the fuzzy logic controller's control signal and the system's output signal with regard to water. with zero noise

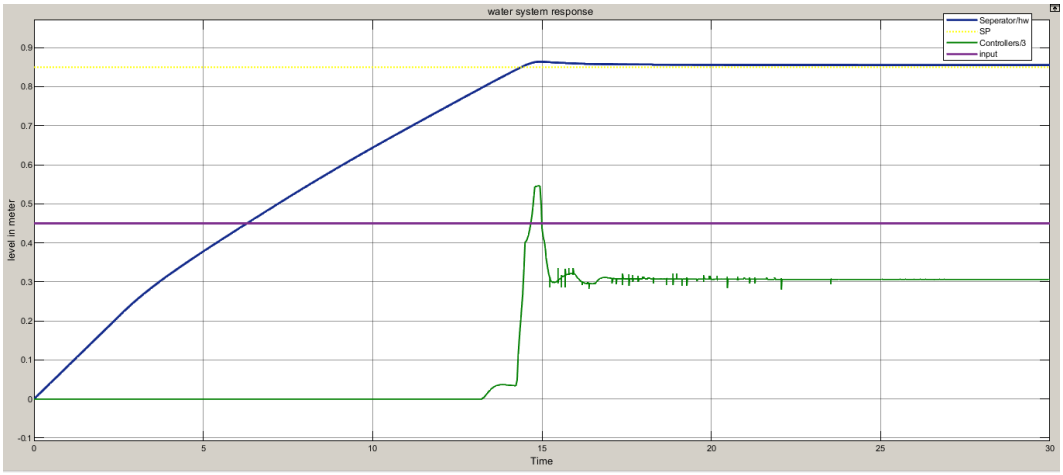

Figure 4.12 fuzzy logic controller for water with zero noise

4.2.4. Fuzzy Logic Controller with 25% Noise (Gas Section)

In this specific situation, the signal at the output of the system and the control signal are both stable. The signal at the controller, on the other hand, is subject to some oscillations, but these do not have an impact on the overall stability of the system.

Figure 4.13 shows the control signal of the fuzzy logic controller and the output signal of the system in relation to natural gas when the system is distorted by 25%.

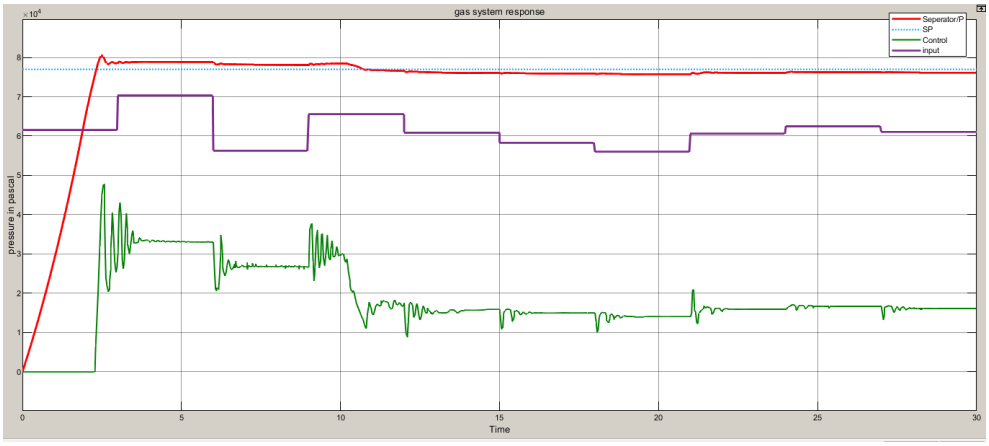

Figure 4.13 fuzzy logic controller for gas with 25% noise

4.2.5. Fuzzy Logic Controller with 25% Noise (Oil Section)

In this specific case, the signal that is obtained at the controller and the signal that is obtained at the output of the system are both totally stable. This is the case regardless of where the signals are obtained.

The control signal as well as the output signal of the system in connection to the crude oil are displayed in the following figure 4.14 when there is 25 percent noise in the system. This is the situation when the fuzzy logic controller is operating at its total capacity.

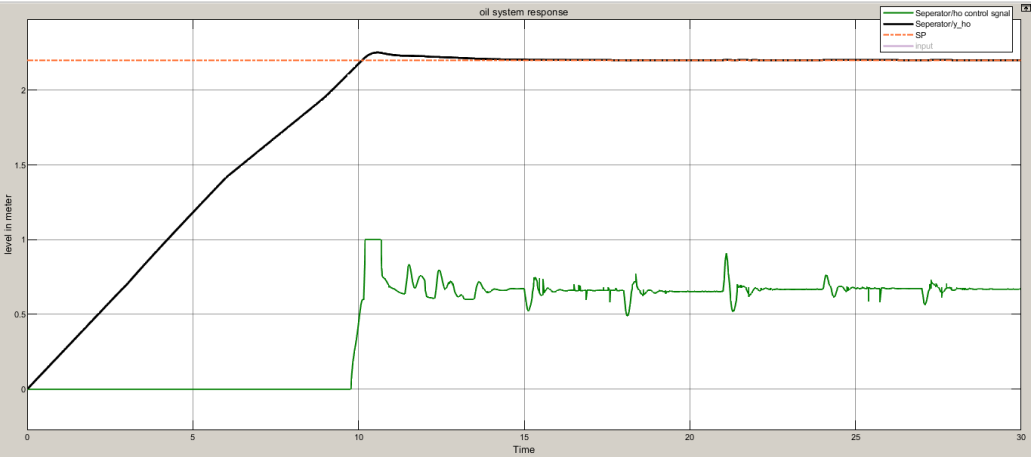

Figure 4.14 fuzzy logic controller for oil with 25% noise

4.2.6. Fuzzy Logic Controller with 25% Noise (Water Section)

The processing of both the output and controller signals by the fuzzy logic controller is of a very top standard. In this specific case, we are able to declare that the system is in a state of total stability.

Figure 4.15 shows the control signal of the fuzzy logic controller as well as the output signal of the system in relation to water when there is a 25 percent distortion in the system. with a total of 25% noise.

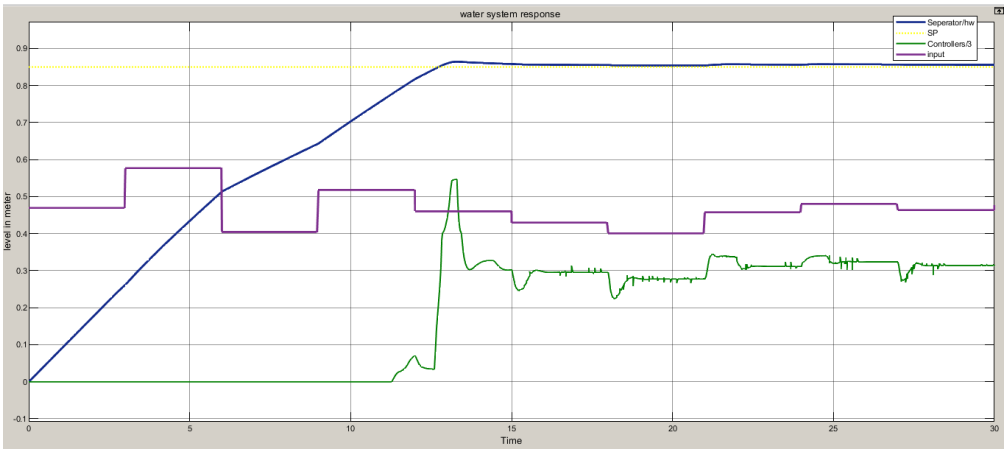

Figure 4.15 fuzzy logic controller for water with 25% noise

4.2.7. Fuzzy Logic Controller with 50% Noise (Gas Section)

In this situation, the signal that is transmitted by the system stable; on the other hand, the signal that is produced by the controller is only marginally stable and displays a sizeable degree of variation. This is because the input can be changed by a ratio of fifty percent, which is the reason for this result.

Figure 4.16 illustrates both the control signal and the output signal of the system in relation to the natural gas that is being controlled by the fuzzy logic controller. When there is a noise level of 50 percent in the system, this is the situation.

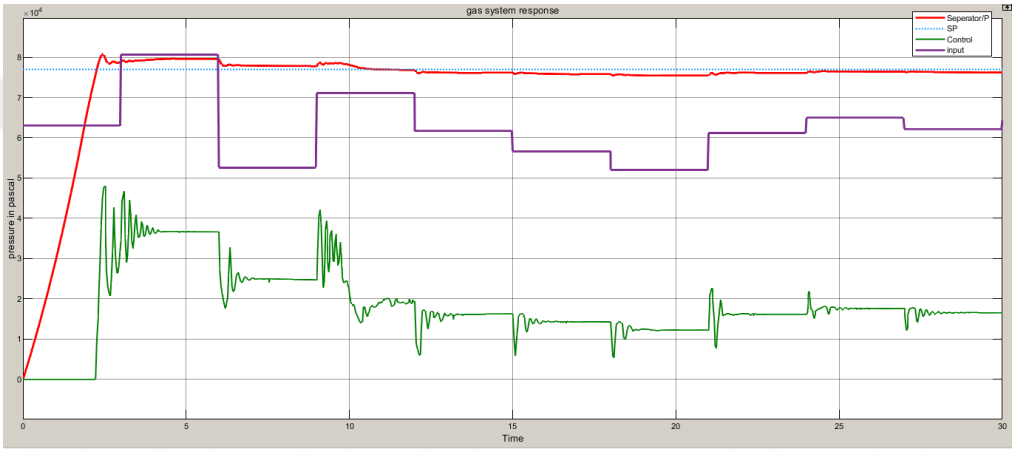

Figure 4.16 fuzzy logic controller for gas with 50% noise

4.2.8. Fuzzy Logic Controller with 50% Noise (Oil Section)

In this particular circumstance, the signal that is received at the controller as well as the signal that is obtained at the output of the system are both completely steady. It makes no difference where the signals come from because this is always the case.

When there is 50 percent noise in the system, both the control signal and the output signal of the system in connection with the crude oil are displayed in the following figure 4.17. The figure describes the situation in which there is noise. This is the state that the fuzzy logic controller is in when it is functioning to the fullest extent of its capabilities.

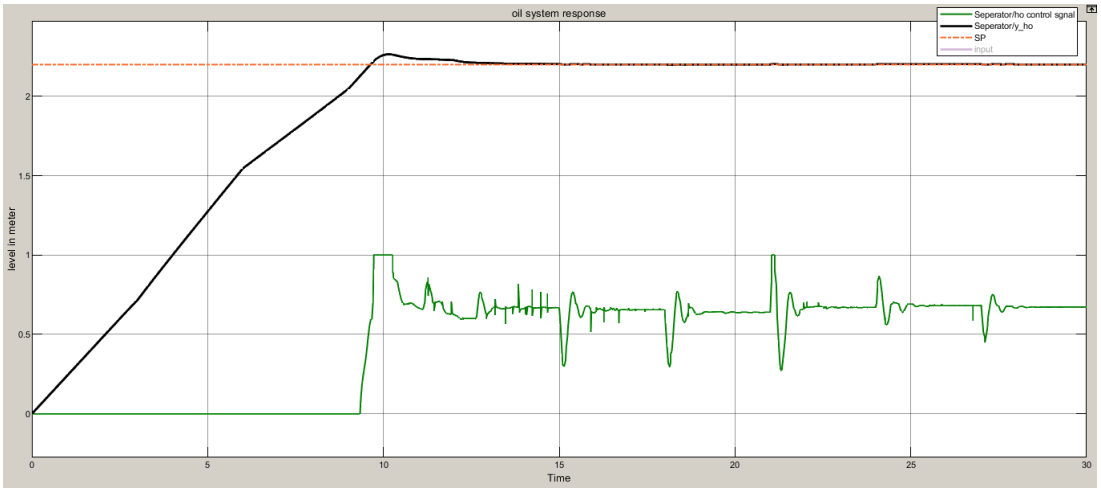

Figure 4.17 fuzzy logic controller for oil with 50% noise

4.2.9. Fuzzy Logic Controller with 50% Noise (Water Section)

In the case of water, there is a degree of total stability, in comparison to the cases of oil and gas, which both have different degrees of stability. The control signal shows a level of volatility that is accepted as normal.

The control signal of the fuzzy logic controller and the system output signal are depicted in Figure 4.18 with regard to water when there is a fifty percent distortion in the system. Considering that the system is "50% noisy".

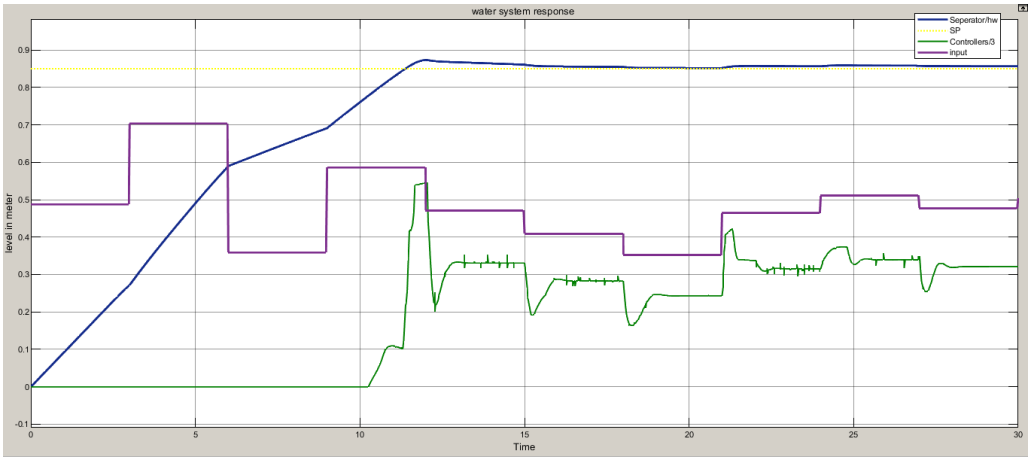

Figure 4.18 fuzzy logic controller for water with 50% noise

4.3. ANFIS RESULTS

4.3.1. ANFIS Controller with Zero Noise (Gas Section)

The ANFIS controller significantly outperformed fuzzy logic as well as the PID controller when it refers to speed and stability. In this particular case, the signal that is received at the controller as well as the signal that is received at the output of the system are both completely stable.

When there is no noise in the system, figure 4.19 demonstrates both the control signal and the output signal of the system with regard to the natural gas of the ANFIS controller. This occurs when there is no noise in the system.

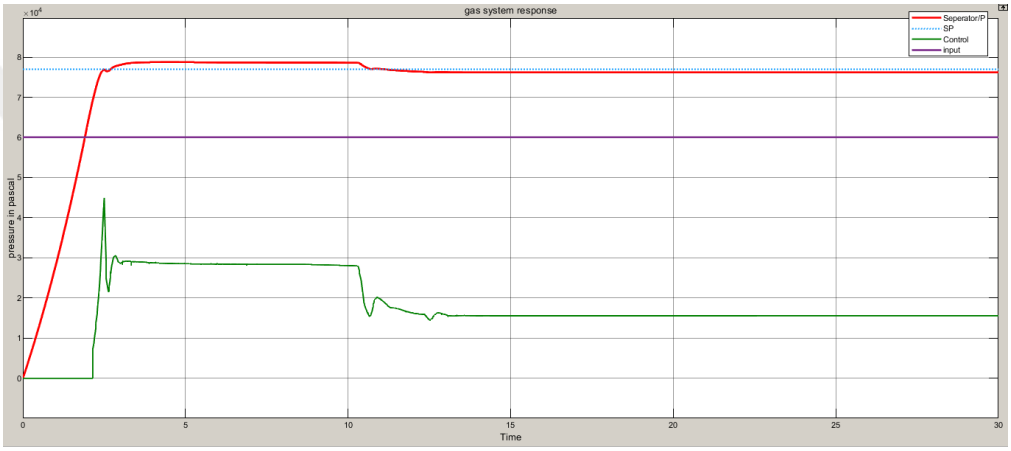

Figure 4.19 ANFIS controller for gas with zero noise

4.3.2. ANFIS Controller with Zero Noise (Oil Section)

In comparison to their equivalent, the ANFIS controller, the fuzzy logic controller and the PID controller are both generally slower and less stable. In this case, both the signal that is received at the controller and the signal that is obtained at the output of the system are totally stable. This is the case because the situation has been brought to a state in which it is possible for both signals to be obtained.

Figure 4.20 represents the control signal and the output signal of the system in relation to the crude oil when there is no noise in the system. The control signal is shown first, followed by the output signal. This is the situation when the ANFIS controller is operating at its highest ability.

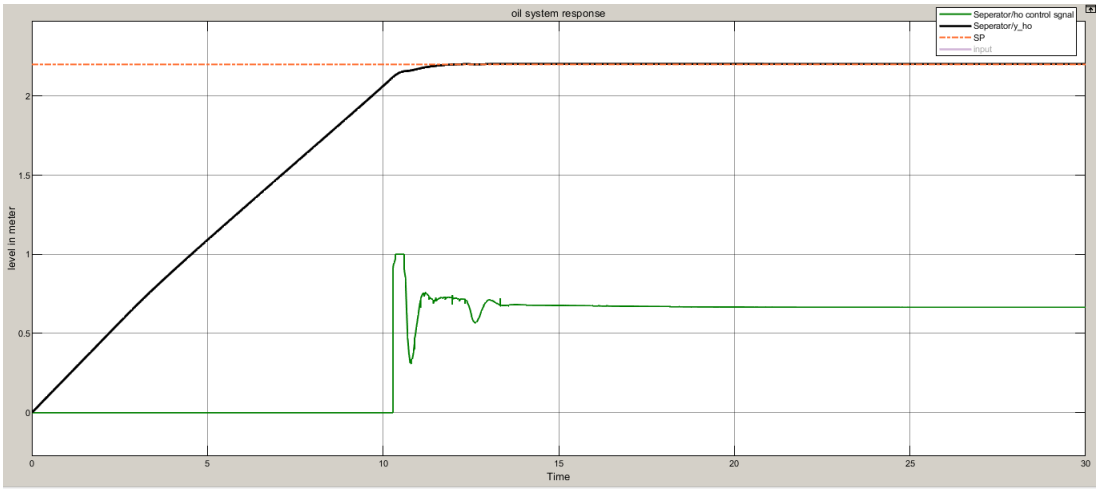

Figure 4.20 ANFIS controller for oil with zero noise

4.3.3. ANFIS Controller with Zero Noise (Water Section)

The control signal and the system signal both display total and complete stability. This is due to the fact that the controller's ANFIS has the capability to dampen oscillations that can be minimized within an appropriate period of time. However, the period of time of the event is longer than the time period covered by fuzzy logic. And there is not a single case of steady-state error.

Figure 4.21 illustrates the control signal from the ANFIS controller as well as the output signal from the system in relation to water when there is no distortion in the system. without producing any noise.

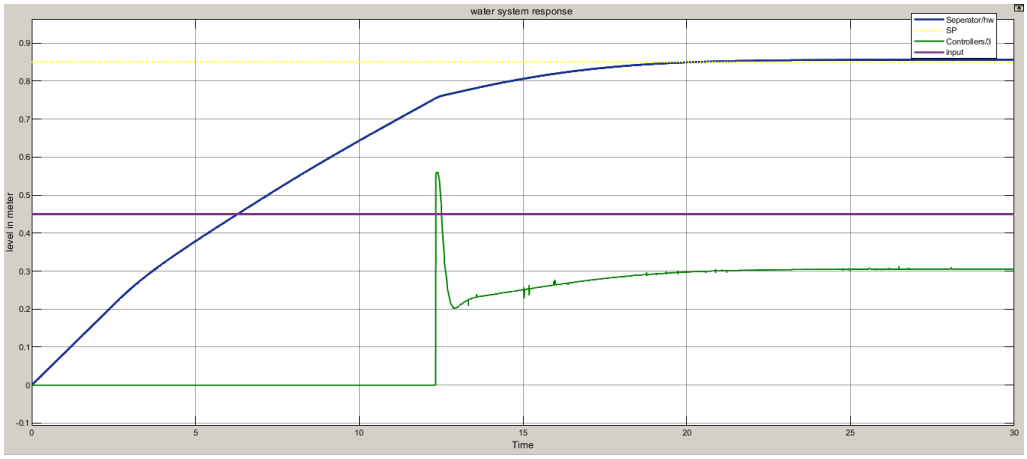

Figure 4.21 ANFIS controller for water with zero noise

4.3.4. ANFIS Controller with 25% Noise (Gas Section)

Therefore, in case, both the signal that is received at the output of the system as well as the signal that is used for control are stable. On the other hand, the signal that is received at the controller is subject to some oscillations; however, these oscillations do not have an effect on the system as a whole and its ability to remain stable.

When the system is distorted by 25%, both the control signal of the ANFIS controller and the output signal of the system are depicted in Figure 4.22. Both signals are in relation to natural gas.

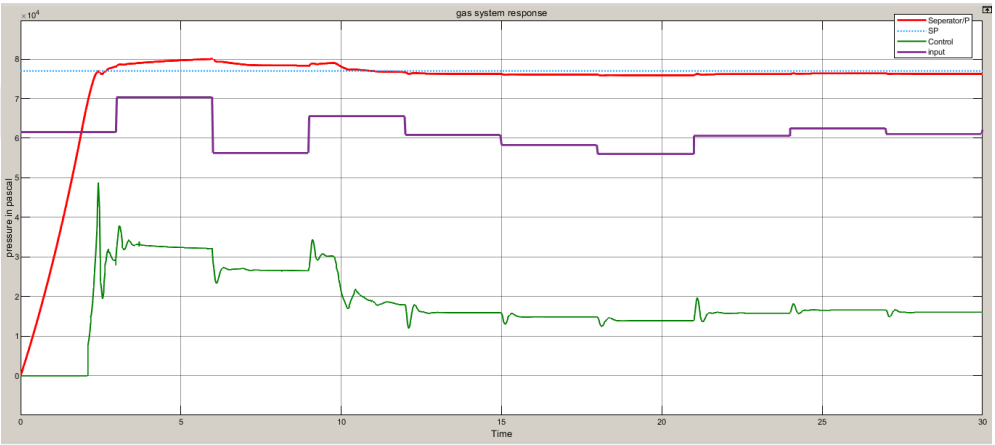

Figure 4.22 ANFIS controller for gas with 25% noise

4.3.5. ANFIS Controller with 25% Noise (Oil Section)

In this particular case, the signal that is obtained at the ANFIS controller as well as the signal that is obtained at the output of the system are both completely stable.

When there is 25 percent noise in the system, both the control signal and the output signal of the system in connection with the crude oil are displayed in figure 4.23 below. The figure describes the situation in which there is noise. When the ANFIS controller is working at its absolute maximum capability, this is the situation that occurs.

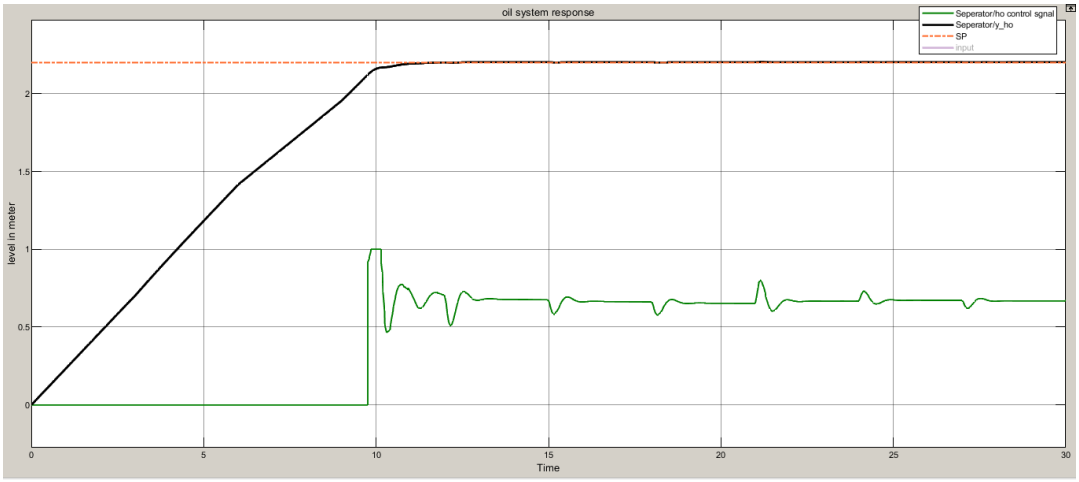

Figure 4.23 ANFIS controller for oil with 25% noise

4.3.6. ANFIS Controller with 25% Noise (Water Section)

Both the control signal and the system signal show absolute and total stability. This is because the controller's ANFIS has the capability to dampening fluctuations that can be decreased within a suitable amount of time. The reason for this is as follows: However, the length of time that the event will be occurring limits the time span that is covered by fuzzy logic. And not a single case of steady-state error can be found anywhere.

Figure 4.24 depicts the control signal from the ANFIS controller as well as the output signal from the system in relation to water when there is a 25 percent noise in the system. Also depicted in this figure is the relationship between the multi signals.

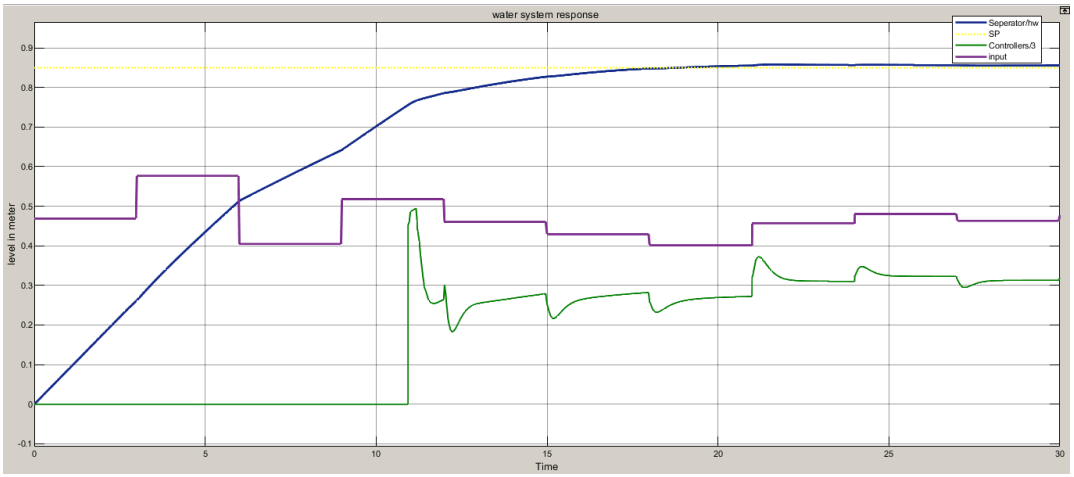

Figure 4.24 ANFIS controller for water with 25% noise

4.3.7. ANFIS Controller with 50% Noise (Gas Section)

Even though there is a significant amount of variation in the input signal of the system around fifty percent the ANFIS controller is operating correctly, and all of the signals are maintaining stability. It is possible for it to be acceptable with some fluctuation.

Figure 4.25 illustrates the control signal of the ANFIS controller as well as the output signal of the system at the point in time when the system has been distorted by a ratio of 50%. The natural gas industry is relevant to both signals.

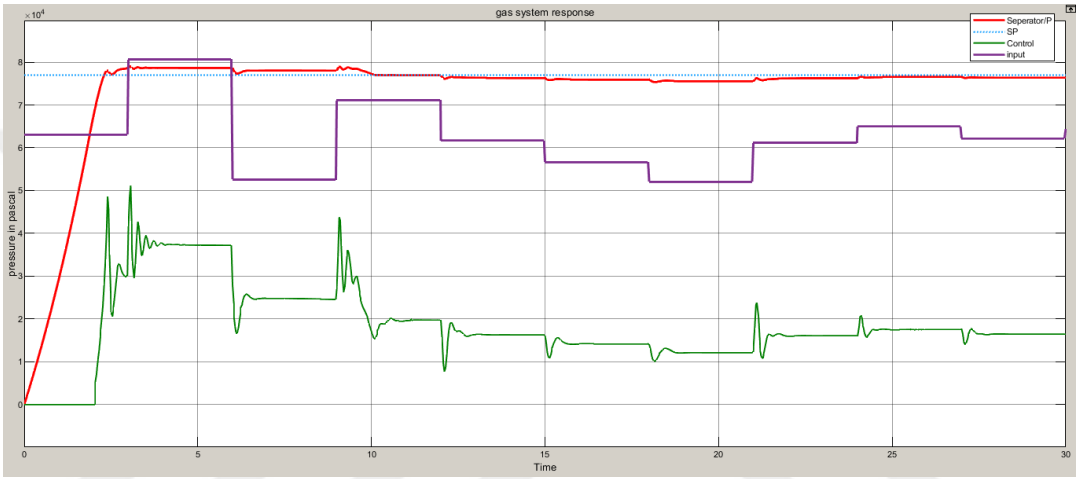

Figure 4.25 ANFIS controller for gas with 50% noise

4.3.8. ANFIS Controller With 50% Noise (Oil Section)

Both the signal that is obtained at the ANFIS controller and the signal that is received at the output of the system are fully stable in this particular case involving crude oil. It makes no difference where the signals come from because this is always the case.

When there is 50% noise in the system, the control signal of the system as well as the output signal of the system in connection with the crude oil are displayed in the following figure 4.26. This figure can be seen below. When the ANFIS controller is working at its absolute maximum capability, this is the situation that occurs.

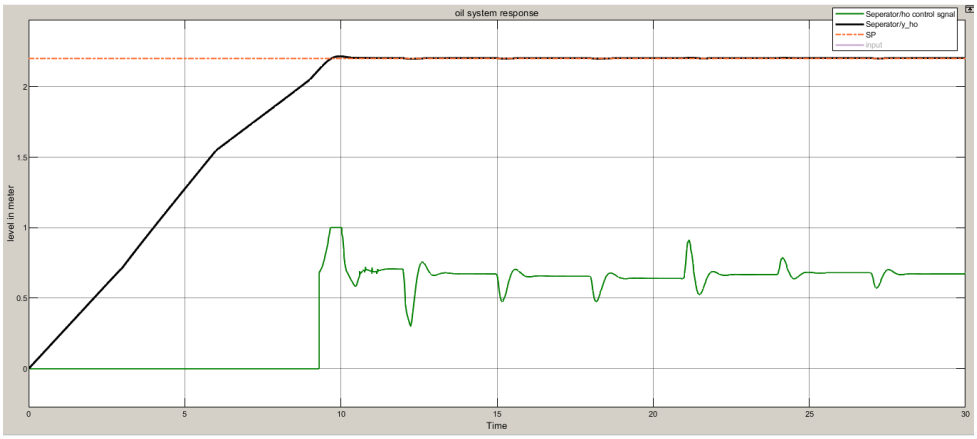

Figure 4.26 ANFIS controller for oil with 50% noise

4.3.9. ANFIS Controller with 50% Noise (Water Section)

Even though the disturbance level is very high in this situation, at 50%, the controller is nevertheless able to a significant amount of control on the system, as can be seen in figure 4.27 below.

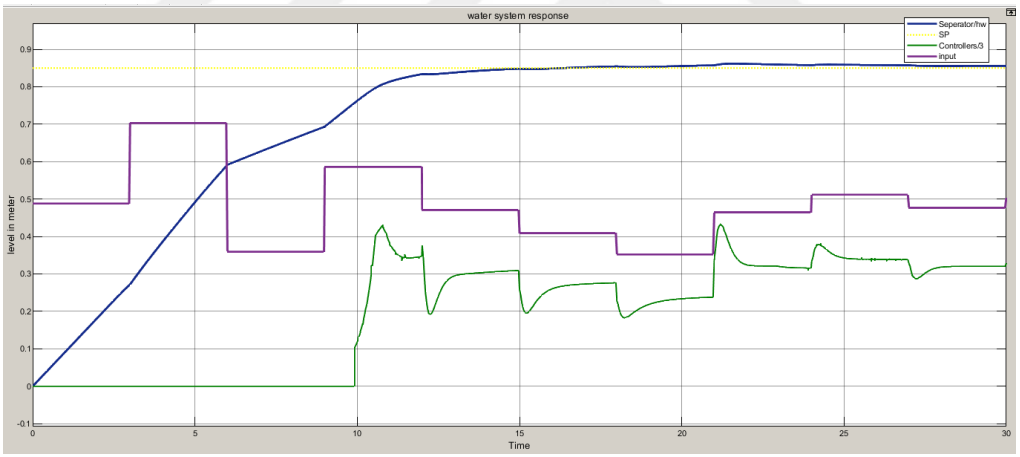

Figure 4.27 ANFIS controller for water with 50% noise

4.4. COMPARE RESULTS BETWEEN PID, FUZZY LOGIC, AND ANFIS

The following was determined based on the comparison of the results of the controllers:

The three controllers are performing their work efficiently without disturbing with the input to the system. The results obtained from the various controllers differ when there is moderate noise present; nonetheless, in general, the performance of all of the controllers is satisfactory.

In the presence of noise at a high level, the ANFIS controller performs at a high level, fuzzy logic works at an acceptable level, but the results from the PID controllers are unacceptable.

A comparison of the results obtained by the PID, fuzzy logic, and ANFIS controllers is presented in the following figure 4.28.

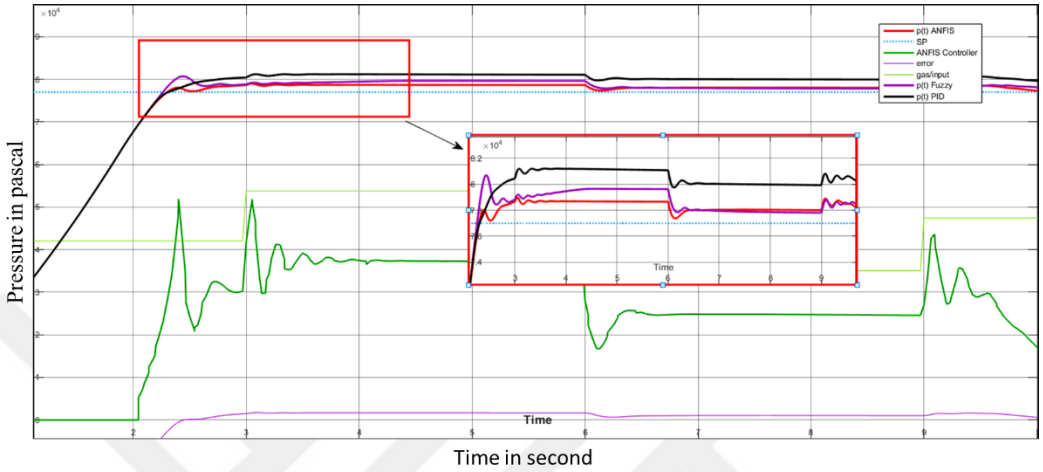

Figure 4.28 comparison of the results

We can compare the error rate of the system's output between the controllers in two different situations by taking the square root of the error. The first situation is when there is no noise, and the second situation is when there is a high amount of noise.

The square root of the error that occurred in the aforementioned two cases is presented in Table 4.1

Table 4.1 square root of the error for PID, fuzzy logic, ANFIS controller

Results after dead zone							
Controller	Square Root Error			Square Root Error			
	Gas	Oil	Water	Gas	Oil	Water	Error Summation
PID	5451202832	90.11411819	17.51465847	545.1202832	90.11411819	17.51465847	652.7490598
Fuzzy	1383187798	82.03775942	15.80073682	138.3187798	82.03775942	15.80073682	236.1572761
ANFIS	1140367408	170.3311201	28.25643721	114.0367408	170.3311201	28.25643721	312.6242982

Results with dead zone							
Controller	Square Root Error			Square Root Error			
	Gas	Oil	Water	Gas	Oil	Water	Error Summation
PID	2.73595E+11	619.9699725	96.96527574	27359.46671	90.11411819	17.51465847	27467.09548
Fuzzy	2.68911E+11	596.5811873	92.94031457	26891.10036	82.03775942	15.80073682	26988.93886
ANFIS	2.73595E+11	619.9699725	96.96527574	27359.46671	170.3311201	28.25643721	27558.05427

The following figure 4.29 shows the percentage of error in the three cases.

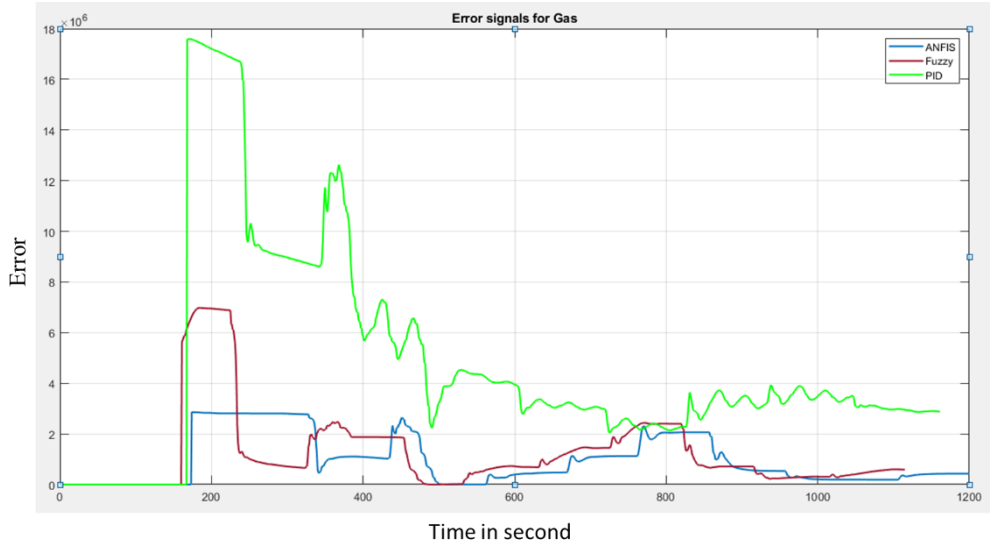

Figure 4.29 square root of the error for PID, fuzzy logic, and ANFIS

5. DISCUSSION

In our thesis, we focused on the three-phase separator control systems used in oil and gas processing plants. particularly those where a sudden change in the pressure of the wells that feed those systems and separators produces a significant fluctuation in pressure and the amount of fluid entering the separators, resulting in the controller failing to maintain system stability. to deal with large disturbances in the system.

The other challenge is to develop a method for tuning the system according to its capabilities and making use of more intelligent controllers than are now utilized in order to prevent the system from breaking down and guarantee that it performs appropriately.

The most difficult challenge that we had to overcome while researching on this thesis was determining the mathematical model that would act as a representation of the entire system. This model needed to include all of the processing parameters. It handles all of the components that make up a multiple-input, multiple-output (MIMO) system in order to verify and develop the system structure, and it is compatible with the actual practical system.

Despite the fact that the vast majority of the research, some of which is funded by companies, and research papers, some of which are published in the most highly regarded scientific journals, deal with the system on the basis that it is a single-input, single-output (SISO) system, it is important to note that there are exceptions to this rule.

That is not even close to being accurate. For example, gas pressure is what determines the flow velocity, and this in turn impacts the amount of oil and water that is present. And if there is an increase in the water level, there will also be an increase in the oil level. In other words, simplifying the process and making accommodations for it are not acceptable. It is not accurate to think of the system as also being linear.

MATLAB and SIMULINK are the settings in which the model is actually implemented, as well as the settings in which the simulations are done. Because of their capacity to create and apply various conditions and factors, MATLAB and SIMULINK are among the most essential pieces of software utilized in the depiction of industrial systems in universities and research centers.

This is due to the fact that these programs may be found. in addition to the potential for the creation of a variety of controllers.

The proportional, integral, and derivative controller, also known as the PID controller, was designed of, constructed, and built in such a way that it would be compatible with the system and would benefit from its use in contrast to modern controllers. This is due to the fact that PID controllers are actually used in practical systems.

The system must be transformed from a non-linear system into a linear system in the proximity of the set point. This is the most important aspect to consider. The PID controller is able to function normally on a non-linear system by utilizing this method, which is known as linearization.

Even though the PID controller has a lot of good points, it can't handle sudden and continuous changes well enough to do some tasks. As a result, it was speculated that more advanced intelligent controllers than the PID should be used.

The operation of intelligent controllers is also supported by linearization, even though that intelligent controllers are able to operate on non-linear systems, in contrast to PID controllers, which are only able to work on linear systems. Intelligent controllers are designed to manage on non-linear systems. Utilize linearization given that intelligent controllers are capable of carrying out their functions in the most effective manner when operating with linear systems.

The employment of an intelligent fuzzy logic controller, as opposed to a PID controller, helps the system to be more stable, achieve the condition of total stability more rapidly, and have the lowest steady-state error possible. All of this is completed with the high amount of stability that is acceptable.

The signal coming from the fuzzy logic controller is highly volatile whenever there is a rise in the level of noise. This is true despite the fact that the fuzzy logic controller has a performance that is perfect. Smoothing out the signal coming from the fuzzy logic controller is one way that this problem can be fixed without having an effect on the stability of the system.

An ANFIS controller, Adaptive Neuro-Fuzzy Inference System controller, is able to solve all of the problems that were encountered by previous controllers, such as the inability to stabilize the system and fluctuations in the control signal. This is made possible by the use of neuro-fuzzy inference systems. This is as a result of the fact that it possesses a wide variety of traits, each of which, when combined, contribute to its overall usefulness.

Employing intelligent controllers and operating the systems under favorable settings, which include fewer problems and shorter periods of time during which they are exposed to shutdowns, can help resolve issues that arise with separators. These favorable situations include: In addition, the utilization of intelligent control is possible in systems that are similar.

6. CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

When it comes to establishing credibility and reliability in one's work and one's research, one of the most important factors is the development and application of an acceptable mathematical model for the system under investigation. This is true both for the results of one's research and for the functioning of a system.

Because the vast large majority of industrial systems are non-linear, this fact needs to be addressed and researched in order to determine the best way to transform them into linear systems in the region close to the set point. This will make it simpler to work with both classic controllers and modern controllers.

The implementation of intelligent controllers into the manufacturing industry made it possible to control complex systems in a smoother and more stable way than was previously possible. This resulted in an increase in production and a reduction in the amount of system downtime that was caused by the loss of control of industrial systems.

In addition to the fact that it is one of the intelligent controllers, the fuzzy logic controller is simple to comprehend and employ, which is one of the reasons why it is so frequently employed in industrial settings. There are no complicated equations or challenging mathematics forced to participate.

Utilizing a number of intelligent controllers, such as the ANFIS controller, is one way we may achieve the highest possible level of stability. The existence of many intelligent controllers and methods can provide a solution to the vast majority of the problems that happen within the system.

Using intelligent controllers and operating the systems in advantageous situations, which include fewer complications and shorter time periods during which they are exposed to shutdowns, can help to resolve issues that arise with separators.

These factors contribute to fewer problems and shorter amounts of time. In addition, the implementation of intelligent control is achievable in systems that are comparable to the one being controlled.

6.2. RECOMMENDATIONS

Avoiding the use of mathematical models on complex systems is something we recommend doing whenever it is possible to work with the actual system instead. select a strategy for system identification. In order to minimize the amount of work and time spent.

We also recommend using a multi-stage intelligent controller as an example of an ANFIS (adaptive neuro fuzzy inference system). Because of its advantages and characteristics that can be used in solving system problems.

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APPENDICES

APPENDIX-1: Data for ANFIS

0	-77000	0	4.308754	0		0	-77000	0	4.308754	0		0	-77000	0	4.308754	0
3.16E-30	-77000	0	4.308754	0		3.16E-30	-77000	0	4.308754	0		3.16E-30	-77000	0	4.308754	0
7.62E-09	-77000	0.001909	4.308754	0		7.62E-09	-77000	0.001909	4.308754	0		7.62E-09	-77000	0.001909	4.308754	0
4.57E-08	-77000	0.006873	4.308754	0		4.57E-08	-77000	0.006873	4.308754	0		4.57E-08	-77000	0.006873	4.308754	0
2.36E-07	-77000	0.037189	4.308754	0		2.36E-07	-77000	0.037189	4.308754	0		2.36E-07	-77000	0.037189	4.308754	0
1.19E-06	-77000	0.187885	4.308754	0		1.19E-06	-77000	0.187885	4.308754	0		1.19E-06	-77000	0.187885	4.308754	0
5.95E-06	-77000	0.941437	4.308754	0		5.95E-06	-77000	0.941437	4.308754	0		5.95E-06	-77000	0.941437	4.308754	0
2.98E-05	-77000	4.708815	4.308754	0		2.98E-05	-76999.9999	4.708815	4.308754	0		2.98E-05	-77000	4.708815	4.308754	0
0.00014887	-77000	23.53669	4.308754	0		0.00014887	-76999.9971	23.53669	4.308754	0		0.00014887	-77000	23.53669	4.308754	0
0.00074438	-76999.9	117.4511	4.308754	0		0.00074438	-76999.9271	117.4511	4.308754	0		0.00074438	-76999.9	117.4511	4.308754	0
0.00372189	-76998.2	581.4501	4.308754	0		0.00372189	-76998.1959	581.4501	4.308754	0		0.00372189	-76998.2	581.4501	4.308754	0
0.01027372	-76986.5	1779.215	4.308754	0		0.01027372	-76986.5388	1779.215	4.308754	0		0.01027372	-76986.5	1779.215	4.308754	0
0.01810084	-76959.2	3488.248	4.308754	0		0.01810084	-76959.2358	3488.248	4.308754	0		0.01810084	-76959.2	3488.248	4.308754	0
0.02742164	-76909.1	5376.62	4.308754	0		0.02742164	-76909.1214	5376.62	4.308754	0		0.02742164	-76909.1	5376.62	4.308754	0
0.03845036	-76827.2	7423.776	4.308754	0		0.03845036	-76827.2466	7423.776	4.308754	0		0.03845036	-76827.2	7423.776	4.308754	0
0.05169737	-76699.8	9617.295	4.308754	0		0.05169737	-76699.8463	9617.295	4.308754	0		0.05169737	-76699.8	9617.295	4.308754	0
0.0680077	-76504.7	11965.08	4.308754	0		0.0680077	-76504.6919	11965.08	4.308754	0		0.0680077	-76504.7	11965.08	4.308754	0
0.08881449	-76203.4	14481.24	4.308754	0		0.08881449	-76203.3837	14481.24	4.308754	0		0.08881449	-76203.4	14481.24	4.308754	0
0.1	-76020.6	16343.8	4.308754	0		0.1	-76020.5701	16343.8	4.308754	0		0.1	-76020.6	16343.8	4.308754	0
0.14188294	-75232.7	18811.44	4.308754	0		0.14188294	-75232.6915	18811.44	4.308754	0		0.14188294	-75232.7	18811.44	4.308754	0
0.17429582	-74536.1	21490.7	4.308754	0		0.17429582	-74536.116	21490.7	4.308754	0		0.17429582	-74536.1	21490.7	4.308754	0
0.2	-73943.7	23048.28	4.308754	0		0.2	-73943.6788	23048.28	4.308754	0		0.2	-73943.7	23048.28	4.308754	0
0.2364241	-73057.6	24328	4.308754	0		0.2364241	-73057.5532	24328	4.308754	0		0.2364241	-73057.6	24328	4.308754	0
0.25	-72715.9	25169.23	4.308754	0		0.25	-72715.8584	25169.23	4.308754	0		0.25	-72715.9	25169.23	4.308754	0
0.29529806	-71540.2	25953.13	4.308754	0		0.29529806	-71540.2321	25953.13	4.308754	0		0.29529806	-71540.2	25953.13	4.308754	0
0.3	-71415.5	26528.25	4.308754	0		0.3	-71415.4978	26528.25	4.308754	0		0.3	-71415.5	26528.25	4.308754	0
0.32350971	-70785.3	26805.4	4.308754	0		0.32350971	-70785.3107	26805.4	4.308754	0		0.32350971	-70785.3	26805.4	4.308754	0
0.36468334	-69658.6	27364.27	4.308754	0		0.36468334	-69658.6244	27364.27	4.308754	0		0.36468334	-69658.6	27364.27	4.308754	0
0.4	-68672.4	27924.58	4.308754	0		0.4	-68672.4214	27924.58	4.308754	0		0.4	-68672.4	27924.58	4.308754	0
0.44038076	-67525.7	28397.82	4.308754	0		0.44038076	-67525.6958	28397.82	4.308754	0		0.44038076	-67525.7	28397.82	4.308754	0
0.46921953	-66695.6	28785.33	4.308754	0		0.46921953	-66695.5622	28785.33	4.308754	0		0.46921953	-66695.6	28785.33	4.308754	0
0.5	-65800.1	29093.21	4.308754	0		0.5	-65800.0593	29093.21	4.308754	0		0.5	-65800.1	29093.21	4.308754	0
0.53471917	-64778.9	29413	4.308754	0		0.53471917	-64778.8645	29413	4.308754	0		0.53471917	-64778.9	29413	4.308754	0
0.57175806	-63677	29748.24	4.308754	0		0.57175806	-63677.0228	29748.24	4.308754	0		0.57175806	-63677	29748.24	4.308754	0
0.6	-62828.5	30044.26	4.308754	0		0.6	-62828.5145	30044.26	4.308754	0		0.6	-62828.5	30044.26	4.308754	0
0.63134483	-61878.5	30309.39	4.308754	0		0.63134483	-61878.472	30309.39	4.308754	0		0.63134483	-61878.5	30309.39	4.308754	0
0.66821572	-60749.9	30609.49	4.308754	0		0.66821572	-60749.8725	30609.49	4.308754	0		0.66821572	-60749.9	30609.49	4.308754	0
0.7	-59767.4	30909.67	4.308754	0		0.7	-59767.4311	30909.67	4.308754	0		0.7	-59767.4	30909.67	4.308754	0
0.73425486	-58698.8	31197.85	4.308754	0		0.73425486	-58698.7533	31197.85	4.308754	0		0.73425486	-58698.8	31197.85	4.308754	0
0.76972135	-57581.5	31502.51	4.308754	0		0.76972135	-57581.4698	31502.51	4.308754	0		0.76972135	-57581.5	31502.51	4.308754	0
0.8	-56618.9	31790.81	4.308754	0		0.8	-56618.8872	31790.81	4.308754	0		0.8	-56618.9	31790.81	4.308754	0
0.8318002	-55599.2	32064.4	4.308754	0		0.8318002	-55599.233	32064.4	4.308754	0		0.8318002	-55599.2	32064.4	4.308754	0

0.86679631	-54466.7	32360.57	4.308754	0		0.86679631	-54466.739	32360.57	4.308754	0		0.86679631	-54466.7	32360.57	4.308754	0
0.9	-53382.1	32665.11	4.308754	0		0.9	-53382.1367	32665.11	4.308754	0		0.9	-53382.1	32665.11	4.308754	0
0.9339548	-52262.7	32967.35	4.308754	0		0.9339548	-52262.7369	32967.35	4.308754	0		0.9339548	-52262.7	32967.35	4.308754	0
0.96760872	-51142.9	33274.12	4.308754	0		0.96760872	-51142.9322	33274.12	4.308754	0		0.96760872	-51142.9	33274.12	4.308754	0
1	-50055.4	33576.3	4.308754	0		1	-50055.3529	33576.3	4.308754	0		1	-50055.4	33576.3	4.308754	0
1.03214279	-48966.5	33874.08	4.308754	0		1.03214279	-48966.5456	33874.08	4.308754	0		1.03214279	-48966.5	33874.08	4.308754	0
1.06513814	-47838.9	34177.21	4.308754	0		1.06513814	-47838.8563	34177.21	4.308754	0		1.06513814	-47838.9	34177.21	4.308754	0
1.1	-46636.3	34495.81	4.308754	0		1.1	-46636.2683	34495.81	4.308754	0		1.1	-46636.3	34495.81	4.308754	0
1.13375638	-45460.8	34820.91	4.308754	0		1.13375638	-45460.8407	34820.91	4.308754	0		1.13375638	-45460.8	34820.91	4.308754	0
1.16556471	-44343.3	35134.36	4.308754	0		1.16556471	-44343.2753	35134.36	4.308754	0		1.16556471	-44343.3	35134.36	4.308754	0
1.2	-43122.4	35453.92	4.308754	0		1.2	-43122.4094	35453.92	4.308754	0		1.2	-43122.4	35453.92	4.308754	0
1.23238188	-41963.8	35779.13	4.308754	0		1.23238188	-41963.8139	35779.13	4.308754	0		1.23238188	-41963.8	35779.13	4.308754	0
1.26351668	-40840.1	36091.04	4.308754	0		1.26351668	-40840.1267	36091.04	4.308754	0		1.26351668	-40840.1	36091.04	4.308754	0
1.29565568	-39670.1	36404.46	4.308754	0		1.29565568	-39670.1236	36404.46	4.308754	0		1.29565568	-39670.1	36404.46	4.308754	0
1.3	-39511.2	36586.29	4.308754	0		1.3	-39511.181	36586.29	4.308754	0		1.3	-39511.2	36586.29	4.308754	0
1.3217216	-38713.6	36716.89	4.308754	0		1.3217216	-38713.6313	36716.89	4.308754	0		1.3217216	-38713.6	36716.89	4.308754	0
1.36279663	-37192.5	37033.45	4.308754	0		1.36279663	-37192.481	37033.45	4.308754	0		1.36279663	-37192.5	37033.45	4.308754	0
1.4	-35799.9	37431.67	4.308754	0		1.4	-35799.8968	37431.67	4.308754	0		1.4	-35799.9	37431.67	4.308754	0
1.44063355	-34262.7	37831.95	4.308754	0		1.44063355	-34262.6506	37831.95	4.308754	0		1.44063355	-34262.7	37831.95	4.308754	0
1.46810218	-33213.7	38185.54	4.308754	0		1.46810218	-33213.7463	38185.54	4.308754	0		1.46810218	-33213.7	38185.54	4.308754	0
1.49557081	-32156.9	38473.26	4.308754	0		1.49557081	-32156.9385	38473.26	4.308754	0		1.49557081	-32156.9	38473.26	4.308754	0
1.5	-31985.8	38641.23	4.308754	0		1.5	-31985.789	38641.23	4.308754	0		1.5	-31985.8	38641.23	4.308754	0
1.52214597	-31126.9	38781.86	4.308754	0		1.52214597	-31126.9272	38781.86	4.308754	0		1.52214597	-31126.9	38781.86	4.308754	0
1.57065735	-29227.3	39158.33	4.308754	0		1.57065735	-29227.3025	39158.33	4.308754	0		1.57065735	-29227.3	39158.33	4.308754	0
1.6	-28066	39576.94	4.308754	0		1.6	-28066.0104	39576.94	4.308754	0		1.6	-28066	39576.94	4.308754	0
1.64031861	-26455.1	39955.55	4.308754	0		1.64031861	-26455.0582	39955.55	4.308754	0		1.64031861	-26455.1	39955.55	4.308754	0
1.67394917	-25097.7	40361.26	4.308754	0		1.67394917	-25097.6863	40361.26	4.308754	0		1.67394917	-25097.7	40361.26	4.308754	0
1.7	-24037.6	40691.7	4.308754	0		1.7	-24037.6338	40691.7	4.308754	0		1.7	-24037.6	40691.7	4.308754	0
1.73603035	-22559	41038.42	4.308754	0		1.73603035	-22559.0052	41038.42	4.308754	0		1.73603035	-22559	41038.42	4.308754	0
1.78007406	-20731.6	41489.99	4.308754	0		1.78007406	-20731.6317	41489.99	4.308754	0		1.78007406	-20731.6	41489.99	4.308754	0
1.8	-19897.7	41854.04	4.308754	0		1.8	-19897.6508	41854.04	4.308754	0		1.8	-19897.7	41854.04	4.308754	0
1.83014193	-18627.4	42141.42	4.308754	0		1.83014193	-18627.4268	42141.42	4.308754	0		1.83014193	-18627.4	42141.42	4.308754	0
1.85321734	-17647.9	42448.93	4.308754	0		1.85321734	-17647.9003	42448.93	4.308754	0		1.85321734	-17647.9	42448.93	4.308754	0
1.85321734	-17647.9	41984	4.308754	0		1.85321734	-17647.9003	41984	4.308754	0		1.85321734	-17647.9	41984	4.308754	0
1.89359703	-15925.3	42661.29	4.308754	0		1.89359703	-15925.251	42661.29	4.308754	0		1.89359703	-15925.3	42661.29	4.308754	0
1.9	-15652.6	42574.32	4.308754	0		1.9	-15652.6488	42574.32	4.308754	0		1.9	-15652.6	42574.32	4.308754	0
1.93201486	-14297.7	42321.6	4.308754	0		1.93201486	-14297.7289	42321.6	4.308754	0		1.93201486	-14297.7	42321.6	4.308754	0
1.96429408	-12950.6	41732.37	4.308754	0		1.96429408	-12950.6403	41732.37	4.308754	0		1.96429408	-12950.6	41732.37	4.308754	0
1.99970106	-11500	40970.46	4.308754	0		1.99970106	-11500	40970.46	4.308754	0		1.99970106	-11500	40970.46	4.308754	0
1.99970106	-11500	40448	4.308754	0		1.99970106	-11500	40448	4.308754	0		1.99970106	-11500	40448	4.308754	0
1.99970106	-11500	40448	4.308754	0.003076		1.99970106	-11500	40448	4.308754	0.003076		1.99970106	-11500	40448	4.308754	0.003076
2	-11487.9	40544.55	4.308754	0.002109		2	-11487.8798	40544.55	4.308754	0.002109		2	-11487.9	40544.55	4.308754	0.002109

2.00029894	-11475.8	40537.33	4.308754	0.002173		2.00029894	-11475.7617	40537.33	4.308754	0.002173		2.00029894	-11475.8	40537.33	4.308754	0.002173
2.00089681	-11451.5	40526.49	4.308754	0.002266		2.00089681	-11451.532	40526.49	4.308754	0.002266		2.00089681	-11451.5	40526.49	4.308754	0.002266
2.00209255	-11403.1	40504.81	4.308754	0.002451		2.00209255	-11403.0986	40504.81	4.308754	0.002451		2.00209255	-11403.1	40504.81	4.308754	0.002451
2.00448404	-11306.3	40461.4	4.308754	0.002828		2.00448404	-11306.3356	40461.4	4.308754	0.002828		2.00448404	-11306.3	40461.4	4.308754	0.002828
2.00926702	-11113.2	40374.42	4.308754	0.003602		2.00926702	-11113.2257	40374.42	4.308754	0.003602		2.00926702	-11113.2	40374.42	4.308754	0.003602
2.01883298	-10728.7	40200	4.308754	0.005228		2.01883298	-10728.6743	40200	4.308754	0.005228		2.01883298	-10728.7	40200	4.308754	0.005228
2.03796489	-9966.26	39850.24	4.308754	0.008786		2.03796489	-9966.26296	39850.24	4.308754	0.008786		2.03796489	-9966.26	39850.24	4.308754	0.008786
2.07290966	-8596.69	39192.46	4.308754	0.01651		2.07290966	-8596.69105	39192.46	4.308754	0.01651		2.07290966	-8596.69	39192.46	4.308754	0.01651
2.07290966	-8596.69	38912	4.308754	0.01989		2.07290966	-8596.69105	38912	4.308754	0.01989		2.07290966	-8596.69	38912	4.308754	0.01989
2.1	-7555.25	38443.3	4.308754	0.026454		2.1	-7555.24923	38443.3	4.308754	0.026454		2.1	-7555.25	38443.3	4.308754	0.026454
2.12709034	-6531.49	37790.75	4.308754	0.036201		2.12709034	-6531.48507	37790.75	4.308754	0.036201		2.12709034	-6531.49	37790.75	4.308754	0.036201
2.18127101	-4537.54	36801.72	4.308754	0.053752		2.18127101	-4537.5434	36801.72	4.308754	0.053752		2.18127101	-4537.54	36801.72	4.308754	0.053752
2.2	-3865.22	35897.51	4.308754	0.069168		2.2	-3865.21923	35897.51	4.308754	0.069168		2.2	-3865.22	35897.51	4.308754	0.069168
2.24730324	-2208.47	35023.92	4.308754	0.088303		2.24730324	-2208.47443	35023.92	4.308754	0.088303		2.24730324	-2208.47	35023.92	4.308754	0.088303
2.28379381	-974.272	33822.49	4.308754	0.113631		2.28379381	-974.272485	33822.49	4.308754	0.113631		2.28379381	-974.272	33822.49	4.308754	0.113631
2.3	-439.708	32985.21	4.308754	0.130978		2.3	-439.707684	32985.21	4.308754	0.130978		2.3	-439.708	32985.21	4.308754	0.130978
2.33760234	763.9713	32010.75	4.308754	0.155233		2.33760234	763.9712564	32010.75	4.308754	0.155233		2.33760234	763.9713	32010.75	4.308754	0.155233
2.37135705	1794.52	30530.51	4.308754	0.190042		2.37135705	1794.519888	30530.51	4.308754	0.190042		2.37135705	1794.52	30530.51	4.308754	0.190042
2.37135705	1794.52	29696	4.308754	0.206428		2.37135705	1794.519888	29696	4.308754	0.206428		2.37135705	1794.52	29696	4.308754	0.206428
2.4	2624.232	28967.4	4.308754	0.227202		2.4	2624.231544	28967.4	4.308754	0.227202		2.4	2624.232	28967.4	4.308754	0.227202
2.42864295	3403.325	27200.19	4.308754	0.27005		2.42864295	3403.325129	27200.19	4.308754	0.27005		2.42864295	3403.325	27200.19	4.308754	0.27005
2.47115152	4438.247	24346.2	4.308754	0.331136		2.47115152	4438.24738	24346.2	4.308754	0.331136		2.47115152	4438.247	24346.2	4.308754	0.331136
2.47115152	4438.247	22016	4.308754	0.379885		2.47115152	4438.24738	22016	4.308754	0.379885		2.47115152	4438.247	22016	4.308754	0.379885
2.5	5030.468	20528.66	4.308754	0.411		2.5	5030.468026	20528.66	4.308754	0.411		2.5	5030.468	20528.66	4.308754	0.411
2.52192688	5398.243	16772.77	4.308754	0.489575		2.52192688	5398.242644	16772.77	4.308754	0.489575		2.52192688	5398.243	16772.77	4.308754	0.489575
2.52192688	5398.243	14336	4.308754	0.540553		2.52192688	5398.242644	14336	4.308754	0.540553		2.52192688	5398.243	14336	4.308754	0.540553
2.55077536	5726.514	11379.17	4.308754	0.525766		2.55077536	5726.514358	11379.17	4.308754	0.525766		2.55077536	5726.514	11379.17	4.308754	0.525766
2.57962385	5826.905	3479.911	4.308754	0.452759		2.57962385	5826.904524	3479.911	4.308754	0.452759		2.57962385	5826.905	3479.911	4.308754	0.452759
2.6	5767.161	-2932.02	4.308754	0.393499		2.6	5767.161266	-2932.02	4.308754	0.393499		2.6	5767.161	-2932.02	4.308754	0.393499
2.64730339	5339.909	-9032.16	4.308754	0.337119		2.64730339	5339.909304	-9032.16	4.308754	0.337119		2.64730339	5339.909	-9032.16	4.308754	0.337119
2.68707566	4829.424	-12835.2	4.308754	0.301971		2.68707566	4829.424171	-12835.2	4.308754	0.301971		2.68707566	4829.424	-12835.2	4.308754	0.301971
2.7	4657.68	-13288.4	4.308754	0.297782		2.7	4657.680157	-13288.4	4.308754	0.297782		2.7	4657.68	-13288.4	4.308754	0.297782
2.73831148	4171.563	-12688.6	4.308754	0.303326		2.73831148	4171.562659	-12688.6	4.308754	0.303326		2.73831148	4171.563	-12688.6	4.308754	0.303326
2.78141406	3699.548	-10951	4.308754	0.319385		2.78141406	3699.548279	-10951	4.308754	0.319385		2.78141406	3699.548	-10951	4.308754	0.319385
2.8	3523.391	-9477.98	4.308754	0.330179		2.8	3523.39108	-9477.98	4.308754	0.330179		2.8	3523.391	-9477.98	4.308754	0.330179
2.82871903	3279.645	-8487.25	4.308754	0.318497		2.82871903	3279.64546	-8487.25	4.308754	0.318497		2.82871903	3279.645	-8487.25	4.308754	0.318497
2.8668287	3003.653	-7242.07	4.308754	0.30836		2.8668287	3003.652701	-7242.07	4.308754	0.30836		2.8668287	3003.653	-7242.07	4.308754	0.30836
2.9	2805.137	-5984.55	4.308754	0.306499		2.9	2805.137451	-5984.55	4.308754	0.306499		2.9	2805.137	-5984.55	4.308754	0.306499
2.9368872	2627.431	-4817.55	4.308754	0.306597		2.9368872	2627.431347	-4817.55	4.308754	0.306597		2.9368872	2627.431	-4817.55	4.308754	0.306597
2.97303309	2492.704	-3727.32	4.308754	0.310052		2.97303309	2492.704123	-3727.32	4.308754	0.310052		2.97303309	2492.704	-3727.32	4.308754	0.310052
3	2413.525	-2936.16	6.066909	0.211023		3	2413.524884	-2936.16	6.066909	0.5		3	2413.525	-2936.16	6.066909	0.5
3.02983434	2424.845	379.4459	6.066909	0.346557		3.02983434	2424.845402	379.4459	6.066909	0.498		3.02983434	2424.845	379.4459	6.066909	0.5

3.05410476	2540.376	4760.145	6.066909	0.53856		3.05410476	2540.376128	4760.145	6.066909	0.496		3.05410476	2540.376	4760.145	6.066909	0.5
3.07837518	2679.524	5733.219	6.066909	0.597297		3.07837518	2679.523782	5733.219	6.066909	0.494		3.07837518	2679.524	5733.219	6.066909	0.5
3.1	2758.13	3634.992	6.066909	0.512718		3.1	2758.129807	3634.992	6.066909	0.492		3.1	2758.13	3634.992	6.066909	0.5
3.1317064	2759.58	45.7455	6.066909	0.351117		3.1317064	2759.580233	45.7455	6.066909	0.49		3.1317064	2759.58	45.7455	6.066909	0.5
3.16440901	2687.394	-2207.35	6.066909	0.247724		3.16440901	2687.394004	-2207.35	6.066909	0.488		3.16440901	2687.394	-2207.35	6.066909	0.5
3.2	2642.105	-1272.48	6.066909	0.287294		3.2	2642.105317	-1272.48	6.066909	0.486		3.2	2642.105	-1272.48	6.066909	0.5
3.24639928	2724.269	1770.805	6.066909	0.426165		3.24639928	2724.269374	1770.805	6.066909	0.484		3.24639928	2724.269	1770.805	6.066909	0.5
3.27354758	2815.25	3351.24	6.066909	0.505432		3.27354758	2815.249833	3351.24	6.066909	0.482		3.27354758	2815.25	3351.24	6.066909	0.5
3.3	2879.803	2440.337	6.066909	0.469206		3.3	2879.802652	2440.337	6.066909	0.48		3.3	2879.803	2440.337	6.066909	0.5
3.33746425	2893.569	367.4431	6.066909	0.373438		3.33746425	2893.568633	367.4431	6.066909	0.478		3.33746425	2893.569	367.4431	6.066909	0.5
3.37504034	2865.585	-744.708	6.066909	0.320192		3.37504034	2865.585432	-744.708	6.066909	0.476		3.37504034	2865.585	-744.708	6.066909	0.5
3.4	2863.865	-68.9467	6.066909	0.351461		3.4	2863.864546	-68.9467	6.066909	0.474		3.4	2863.865	-68.9467	6.066909	0.5
3.43285723	2900.885	1126.718	6.066909	0.409441		3.43285723	2900.885376	1126.718	6.066909	0.472		3.43285723	2900.885	1126.718	6.066909	0.5
3.47268329	2975.622	1876.564	6.066909	0.450369		3.47268329	2975.621541	1876.564	6.066909	0.47		3.47268329	2975.622	1876.564	6.066909	0.5
3.5	3012.151	1337.267	6.066909	0.427172		3.5	3012.151289	1337.267	6.066909	0.468		3.5	3012.151	1337.267	6.066909	0.5
3.53590886	3026.473	398.8473	6.066909	0.38272		3.53590886	3026.473439	398.8473	6.066909	0.466		3.53590886	3026.473	398.8473	6.066909	0.5
3.57735569	3027.443	23.40081	6.066909	0.364584		3.57735569	3027.443328	23.40081	6.066909	0.464		3.57735569	3027.443	23.40081	6.066909	0.5
3.6	3037.783	456.6068	6.066909	0.386192		3.6	3037.782876	456.6068	6.066909	0.462		3.6	3037.783	456.6068	6.066909	0.5
3.63021597	3066.225	941.2843	6.066909	0.41161		3.63021597	3066.224695	941.2843	6.066909	0.46		3.63021597	3066.225	941.2843	6.066909	0.5
3.67090615	3111.425	1110.837	6.066909	0.422976		3.67090615	3111.424855	1110.837	6.066909	0.458		3.67090615	3111.425	1110.837	6.066909	0.5
3.7	3132.502	724.4577	6.066909	0.405167		3.7	3132.50212	724.4577	6.066909	0.456		3.7	3132.502	724.4577	6.066909	0.5
3.73532926	3143.927	323.3947	6.066909	0.385858		3.73532926	3143.927416	323.3947	6.066909	0.454		3.73532926	3143.927	323.3947	6.066909	0.5
3.77471633	3155.463	292.8855	6.066909	0.384997		3.77471633	3155.463315	292.8855	6.066909	0.452		3.77471633	3155.463	292.8855	6.066909	0.5
3.8	3169.583	558.4647	6.066909	0.399157		3.8	3169.583355	558.4647	6.066909	0.45		3.8	3169.583	558.4647	6.066909	0.5
3.8307113	3192.292	739.418	6.066909	0.409685		3.8307113	3192.291845	739.418	6.066909	0.448		3.8307113	3192.292	739.418	6.066909	0.5
3.87013194	3218.883	674.5383	6.066909	0.408062		3.87013194	3218.882574	674.5383	6.066909	0.446		3.87013194	3218.883	674.5383	6.066909	0.5
3.9	3231.512	422.8325	6.066909	0.396		3.9	3231.511761	422.8325	6.066909	0.444		3.9	3231.512	422.8325	6.066909	0.5
3.93465965	3241.472	287.3824	6.066909	0.389657		3.93465965	3241.472334	287.3824	6.066909	0.442		3.93465965	3241.472	287.3824	6.066909	0.5
3.97263661	3255.361	365.7049	6.066909	0.394476		3.97263661	3255.360696	365.7049	6.066909	0.44		3.97263661	3255.361	365.7049	6.066909	0.5
4	3269.249	507.5563	6.066909	0.402595		4	3269.249157	507.5563	6.066909	0.438		4	3269.249	507.5563	6.066909	0.5
4.03136459	3286.048	535.5889	6.066909	0.405056		4.03136459	3286.047683	535.5889	6.066909	0.436		4.03136459	3286.048	535.5889	6.066909	0.5
4.06927589	3302.085	423.0125	6.066909	0.40018		4.06927589	3302.084639	423.0125	6.066909	0.434		4.06927589	3302.085	423.0125	6.066909	0.5
4.1	3311.023	290.9352	6.066909	0.393833		4.1	3311.023362	290.9352	6.066909	0.432		4.1	3311.023	290.9352	6.066909	0.5
4.13409367	3320.327	272.8819	6.066909	0.393425		4.13409367	3320.326908	272.8819	6.066909	0.43		4.13409367	3320.327	272.8819	6.066909	0.5
4.17061162	3333.11	350.0527	6.066909	0.398195		4.17061162	3333.110116	350.0527	6.066909	0.428		4.17061162	3333.11	350.0527	6.066909	0.5
4.2	3344.956	403.0773	6.066909	0.401667		4.2	3344.955904	403.0773	6.066909	0.426		4.2	3344.956	403.0773	6.066909	0.5
4.23190641	3356.793	370.9839	6.066909	0.400675		4.23190641	3356.792667	370.9839	6.066909	0.424		4.23190641	3356.793	370.9839	6.066909	0.5
4.2680147	3367.112	285.7978	6.066909	0.396783		4.2680147	3367.112337	285.7978	6.066909	0.422		4.2680147	3367.112	285.7978	6.066909	0.5
4.3	3374.628	234.986	6.066909	0.394528		4.3	3374.628433	234.986	6.066909	0.42		4.3	3374.628	234.986	6.066909	0.5
4.33373289	3383.203	254.1814	6.066909	0.396031		4.33373289	3383.202704	254.1814	6.066909	0.418		4.33373289	3383.203	254.1814	6.066909	0.5
4.36852109	3393.518	296.5089	6.066909	0.398866		4.36852109	3393.517717	296.5089	6.066909	0.416		4.36852109	3393.518	296.5089	6.066909	0.5
4.4	3402.927	298.8971	6.066909	0.399534		4.4	3402.926674	298.8971	6.066909	0.414		4.4	3402.927	298.8971	6.066909	0.5

4.43228776	3411.243	257.5764	6.066909	0.397809		4.43228776	3411.243241	257.5764	6.066909	0.412		4.43228776	3411.243	257.5764	6.066909	0.5
4.46638162	3418.498	212.8025	6.066909	0.395831		4.46638162	3418.498498	212.8025	6.066909	0.41		4.46638162	3418.498	212.8025	6.066909	0.5
4.5	3425.335	203.3439	6.066909	0.395711		4.5	3425.334591	203.3439	6.066909	0.408		4.5	3425.335	203.3439	6.066909	0.5
4.53354021	3432.809	222.8512	6.066909	0.397177		4.53354021	3432.809066	222.8512	6.066909	0.397177		4.53354021	3432.809	222.8512	6.066909	0.5
4.56642388	3440.511	234.2163	6.066909	0.398223		4.56642388	3440.510957	234.2163	6.066909	0.398223		4.56642388	3440.511	234.2163	6.066909	0.5
4.6	3447.808	217.328	6.066909	0.397729		4.6	3447.807987	217.328	6.066909	0.397729		4.6	3447.808	217.328	6.066909	0.5
4.63253306	3453.898	187.1888	6.066909	0.396449		4.63253306	3453.897813	187.1888	6.066909	0.396449		4.63253306	3453.898	187.1888	6.066909	0.5
4.63980495	3455.157	173.1645	6.066909	0.395764		4.63980495	3455.157046	173.1645	6.066909	0.395764		4.63980495	3455.157	173.1645	6.066909	0.5
4.63980495	3455.157	237.4493	6.066909	0.399228		4.63980495	3455.157046	237.4493	6.066909	0.399228		4.63980495	3455.157	237.4493	6.066909	0.5
4.67190106	3460.534	167.534	6.066909	0.395761		4.67190106	3460.534236	167.534	6.066909	0.395761		4.67190106	3460.534	167.534	6.066909	0.5
4.7	3465.335	170.8599	6.066909	0.396209		4.7	3465.335217	170.8599	6.066909	0.396209		4.7	3465.335	170.8599	6.066909	0.5
4.75541595	3475.44	182.3529	6.066909	0.397396		4.75541595	3475.440475	182.3529	6.066909	0.397396		4.75541595	3475.44	182.3529	6.066909	0.5
4.78727534	3480.929	172.277	6.066909	0.397158		4.78727534	3480.929115	172.277	6.066909	0.397158		4.78727534	3480.929	172.277	6.066909	0.5
4.8	3482.942	158.1844	6.066909	0.396506		4.8	3482.941958	158.1844	6.066909	0.396506		4.8	3482.942	158.1844	6.066909	0.5
4.83969522	3488.716	145.456	6.066909	0.396137		4.83969522	3488.715865	145.456	6.066909	0.396137		4.83969522	3488.716	145.456	6.066909	0.5
4.87393518	3493.49	139.4442	6.066909	0.396075		4.87393518	3493.490428	139.4442	6.066909	0.396075		4.87393518	3493.49	139.4442	6.066909	0.5
4.9	3497.199	142.2988	6.066909	0.396436		4.9	3497.19942	142.2988	6.066909	0.396436		4.9	3497.199	142.2988	6.066909	0.5
4.93589048	3502.337	143.1479	6.066909	0.396768		4.93589048	3502.337068	143.1479	6.066909	0.396768		4.93589048	3502.337	143.1479	6.066909	0.5
4.97977508	3508.202	133.6391	6.066909	0.396575		4.97977508	3508.201767	133.6391	6.066909	0.396575		4.97977508	3508.202	133.6391	6.066909	0.5
5	3510.663	121.705	6.066909	0.39606		5	3510.66324	121.705	6.066909	0.39606		5	3510.663	121.705	6.066909	0.5
5.0302488	3514.175	116.106	6.066909	0.395948		5.0302488	3514.175306	116.106	6.066909	0.395948		5.0302488	3514.175	116.106	6.066909	0.5
5.07083532	3518.86	115.4145	6.066909	0.396169		5.07083532	3518.859578	115.4145	6.066909	0.396169		5.07083532	3518.86	115.4145	6.066909	0.5
5.1	3522.243	116.021	6.066909	0.396389		5.1	3522.243294	116.021	6.066909	0.396389		5.1	3522.243	116.021	6.066909	0.5
5.13506651	3526.165	111.8433	6.066909	0.396377		5.13506651	3526.165247	111.8433	6.066909	0.396377		5.13506651	3526.165	111.8433	6.066909	0.5
5.17439074	3530.201	102.6324	6.066909	0.396094		5.17439074	3530.201189	102.6324	6.066909	0.396094		5.17439074	3530.201	102.6324	6.066909	0.5
5.2	3532.655	95.82374	6.066909	0.395856		5.2	3532.655164	95.82374	6.066909	0.395856		5.2	3532.655	95.82374	6.066909	0.5
5.23097593	3535.564	93.91408	6.066909	0.395911		5.23097593	3535.564239	93.91408	6.066909	0.395911		5.23097593	3535.564	93.91408	6.066909	0.5
5.25	3537.353	94.0408	6.066909	0.396016		5.25	3537.353279	94.0408	6.066909	0.396016		5.25	3537.353	94.0408	6.066909	0.5
5.29544121	3541.57	92.79009	6.066909	0.396179		5.29544121	3541.569772	92.79009	6.066909	0.396179		5.29544121	3541.57	92.79009	6.066909	0.5
5.3	3541.979	89.83742	6.066909	0.396039		5.3	3541.979322	89.83742	6.066909	0.396039		5.3	3541.979	89.83742	6.066909	0.5
5.32279395	3543.971	87.3932	6.066909	0.396014		5.32279395	3543.971359	87.3932	6.066909	0.396014		5.32279395	3543.971	87.3932	6.066909	0.5
5.36886809	3547.734	81.65578	6.066909	0.395904		5.36886809	3547.733578	81.65578	6.066909	0.395904		5.36886809	3547.734	81.65578	6.066909	0.5
5.4	3550.134	77.11287	6.066909	0.395786		5.4	3550.134249	77.11287	6.066909	0.395786		5.4	3550.134	77.11287	6.066909	0.5
5.44033642	3553.184	75.60372	6.066909	0.395869		5.44033642	3553.183832	75.60372	6.066909	0.395869		5.44033642	3553.184	75.60372	6.066909	0.5
5.47244924	3555.567	74.20054	6.066909	0.395899		5.47244924	3555.566621	74.20054	6.066909	0.395899		5.47244924	3555.567	74.20054	6.066909	0.5
5.5	3557.54	71.62164	6.066909	0.395756		5.5	3557.539852	71.62164	6.066909	0.395756		5.5	3557.54	71.62164	6.066909	0.5
5.53568114	3560.008	69.18353	6.066909	0.395622		5.53568114	3560.008399	69.18353	6.066909	0.395622		5.53568114	3560.008	69.18353	6.066909	0.5
5.57759728	3562.896	68.89093	6.066909	0.395606		5.57759728	3562.896041	68.89093	6.066909	0.395606		5.57759728	3562.896	68.89093	6.066909	0.5
5.6	3564.465	70.02804	6.066909	0.395669		5.6	3564.464859	70.02804	6.066909	0.395669		5.6	3564.465	70.02804	6.066909	0.5
5.63042874	3566.606	70.37847	6.066909	0.395688		5.63042874	3566.606387	70.37847	6.066909	0.395688		5.63042874	3566.606	70.37847	6.066909	0.5
5.67119771	3569.426	69.17034	6.066909	0.395621		5.67119771	3569.426391	69.17034	6.066909	0.395621		5.67119771	3569.426	69.17034	6.066909	0.5
5.7	3571.365	67.30183	6.066909	0.395518		5.7	3571.364838	67.30183	6.066909	0.395518		5.7	3571.365	67.30183	6.066909	0.5

5.73488935	3573.687	66.55598	6.066909	0.395477		5.73488935	3573.686933	66.55598	6.066909	0.395477		5.73488935	3573.687	66.55598	6.066909	0.5
5.77449792	3576.338	66.93394	6.066909	0.395498		5.77449792	3576.33809	66.93394	6.066909	0.395498		5.77449792	3576.338	66.93394	6.066909	0.5
5.8	3578.052	67.21046	6.066909	0.395513		5.8	3578.052097	67.21046	6.066909	0.395513		5.8	3578.052	67.21046	6.066909	0.5
5.83109686	3580.126	66.6976	6.066909	0.395485		5.83109686	3580.126183	66.6976	6.066909	0.395485		5.83109686	3580.126	66.6976	6.066909	0.5
5.87061023	3582.713	65.46502	6.066909	0.395417		5.87061023	3582.712927	65.46502	6.066909	0.395417		5.87061023	3582.713	65.46502	6.066909	0.5
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5.97270021	3589.294	64.49577	6.066909	0.395363		5.97270021	3589.293661	64.49577	6.066909	0.395363		5.97270021	3589.294	64.49577	6.066909	0.5
6	3591.047	64.21501	3.257444	0.389652		6	3591.046717	64.21501	3.257444	0.389652		6	3591.047	64.21501	3.257444	0.5
6.03069863	3460.799	-4242.8	3.257444	0.352905		6.03069863	3460.798582	-4242.8	3.257444	0.352905		6.03069863	3460.799	-4242.8	3.257444	0.352905
6.03069863	3460.799	-8192	3.257444	0.323653		6.03069863	3460.798582	-8192	3.257444	0.323653		6.03069863	3460.799	-8192	3.257444	0.323653
6.06228794	3115.421	-10933.4	3.257444	0.279448		6.06228794	3115.420775	-10933.4	3.257444	0.279448		6.06228794	3115.421	-10933.4	3.257444	0.279448
6.09298666	2666.443	-14625.3	3.257444	0.216271		6.09298666	2666.44253	-14625.3	3.257444	0.216271		6.09298666	2666.443	-14625.3	3.257444	0.216271
6.1	2556.682	-15650.3	3.257444	0.206283		6.1	2556.681584	-15650.3	3.257444	0.206283		6.1	2556.682	-15650.3	3.257444	0.206283
6.13175656	2057.903	-15706.3	3.257444	0.168621		6.13175656	2057.902556	-15706.3	3.257444	0.168621		6.13175656	2057.903	-15706.3	3.257444	0.168621
6.17252652	1475.274	-14290.6	3.257444	0.130263		6.17252652	1475.274225	-14290.6	3.257444	0.130263		6.17252652	1475.274	-14290.6	3.257444	0.130263
6.2	1152.269	-11757	3.257444	0.134417		6.2	1152.268503	-11757	3.257444	0.134417		6.2	1152.269	-11757	3.257444	0.134417
6.2335872	848.8623	-9033.39	3.257444	0.144743		6.2335872	848.8622974	-9033.39	3.257444	0.144743		6.2335872	848.8623	-9033.39	3.257444	0.144743
6.27343364	616.8538	-5822.57	3.257444	0.168016		6.27343364	616.853819	-5822.57	3.257444	0.168016		6.27343364	616.8538	-5822.57	3.257444	0.168016
6.3	529.374	-3292.88	3.257444	0.193469		6.3	529.3739914	-3292.88	3.257444	0.193469		6.3	529.374	-3292.88	3.257444	0.193469
6.33193146	479.2231	-1570.58	3.257444	0.211718		6.33193146	479.2230718	-1570.58	3.257444	0.211718		6.33193146	479.2231	-1570.58	3.257444	0.211718
6.37114544	473.4132	-148.157	3.257444	0.228841		6.37114544	473.4132433	-148.157	3.257444	0.228841		6.37114544	473.4132	-148.157	3.257444	0.228841
6.4	491.0964	612.8386	3.257444	0.239061		6.4	491.0964329	612.8386	3.257444	0.239061		6.4	491.0964	612.8386	3.257444	0.239061
6.43344576	519.7374	856.3402	3.257444	0.243473		6.43344576	519.7373806	856.3402	3.257444	0.243473		6.43344576	519.7374	856.3402	3.257444	0.243473
6.47160443	549.7397	786.2528	3.257444	0.244124		6.47160443	549.7397455	786.2528	3.257444	0.244124		6.47160443	549.7397	786.2528	3.257444	0.244124
6.5	565.0606	539.55	3.257444	0.241905		6.5	565.0605736	539.55	3.257444	0.241905		6.5	565.0606	539.55	3.257444	0.241905
6.53233075	573.4729	260.1964	3.257444	0.238951		6.53233075	573.4729186	260.1964	3.257444	0.238951		6.53233075	573.4729	260.1964	3.257444	0.238951
6.57000375	572.087	-36.7894	3.257444	0.235288		6.57000375	572.0869506	-36.7894	3.257444	0.235288		6.57000375	572.087	-36.7894	3.257444	0.235288
6.6	564.4047	-256.107	3.257444	0.232236		6.6	564.4046932	-256.107	3.257444	0.232236		6.6	564.4047	-256.107	3.257444	0.232236
6.63334318	551.7077	-380.798	3.257444	0.230065		6.63334318	551.7076934	-380.798	3.257444	0.230065		6.63334318	551.7077	-380.798	3.257444	0.230065
6.67008552	535.6809	-436.195	3.257444	0.228557		6.67008552	535.6808842	-436.195	3.257444	0.228557		6.67008552	535.6809	-436.195	3.257444	0.228557
6.7	522.8865	-427.699	3.257444	0.227993		6.7	522.8864907	-427.699	3.257444	0.227993		6.7	522.8865	-427.699	3.257444	0.227993
6.73249386	510.4537	-382.619	3.257444	0.227895		6.73249386	510.453735	-382.619	3.257444	0.227895		6.73249386	510.4537	-382.619	3.257444	0.227895
6.76854163	499.1621	-313.241	3.257444	0.228155		6.76854163	499.1620822	-313.241	3.257444	0.228155		6.76854163	499.1621	-313.241	3.257444	0.228155
6.8	491.5891	-240.73	3.257444	0.228648		6.8	491.5890965	-240.73	3.257444	0.228648		6.8	491.5891	-240.73	3.257444	0.228648
6.82987377	486.1831	-180.96	3.257444	0.229099		6.82987377	486.1831265	-180.96	3.257444	0.229099		6.82987377	486.1831	-180.96	3.257444	0.229099
6.82987377	486.1831	-256	3.257444	0.228181		6.82987377	486.1831265	-256	3.257444	0.228181		6.82987377	486.1831	-256	3.257444	0.228181
6.82987377	486.1831	-256	3.257444	0.228181		6.82987377	486.1831265	-256	3.257444	0.228181		6.82987377	486.1831	-256	3.257444	0.228181
6.86313431	481.8306	-130.861	3.257444	0.229487		6.86313431	481.8306358	-130.861	3.257444	0.229487		6.86313431	481.8306	-130.861	3.257444	0.229487
6.89639485	478.7366	-93.0242	3.257444	0.229791		6.89639485	478.7366017	-93.0242	3.257444	0.229791		6.89639485	478.7366	-93.0242	3.257444	0.229791
6.9	478.4549	-78.1362	3.257444	0.229959		6.9	478.4549088	-78.1362	3.257444	0.229959		6.9	478.4549	-78.1362	3.257444	0.229959
6.91802576	477.1594	-71.872	3.257444	0.229969		6.91802576	477.1593614	-71.872	3.257444	0.229969		6.91802576	477.1594	-71.872	3.257444	0.229969

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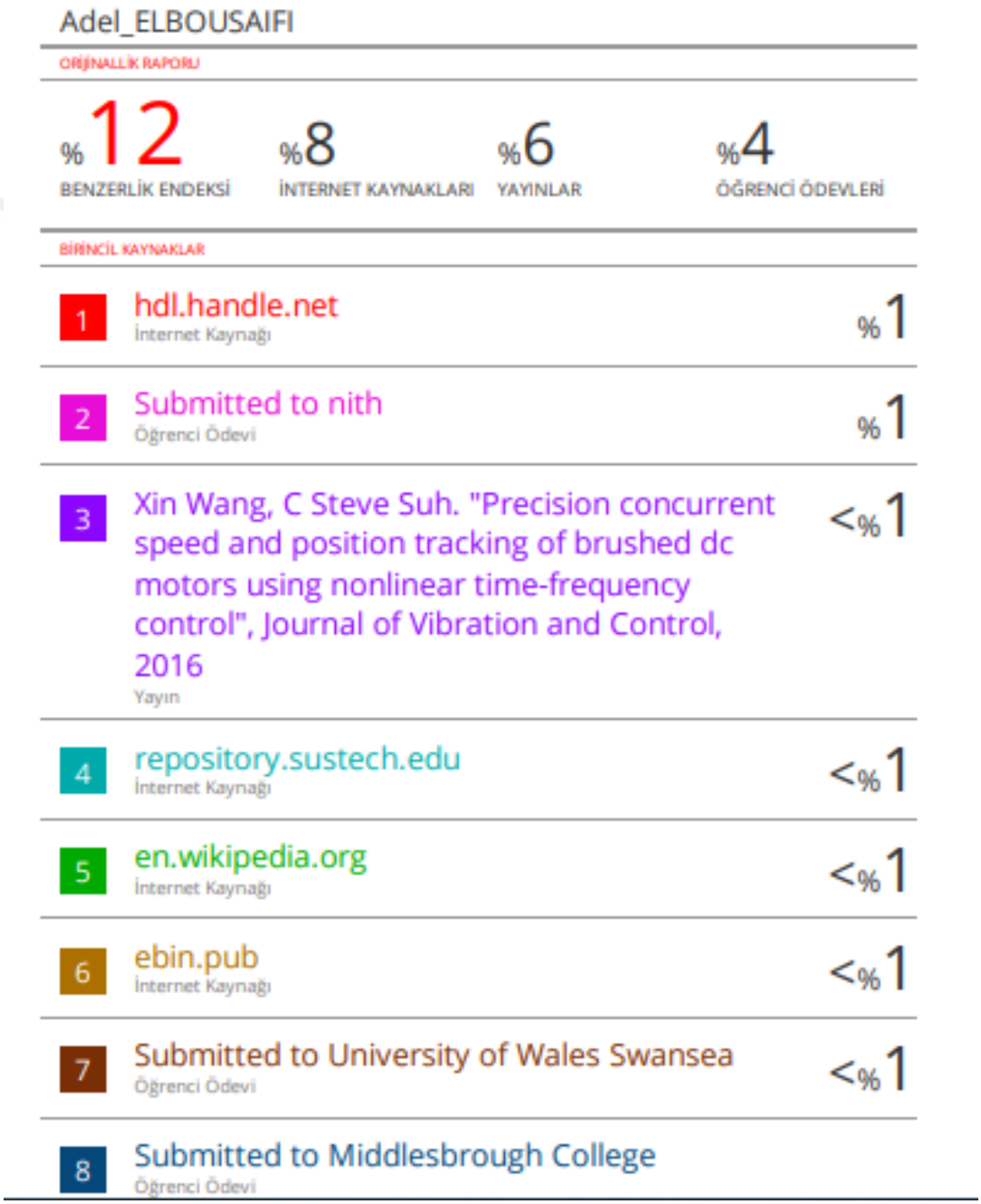

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