CHAPTER ONE
INTRODUCTION

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1.1 Overview

The steam generator or boiler turbine is an integral component of a steam engine when considered as a prime mover. However it needs be treated separately, as to some extent a variety of generator types can be combined with a variety of engine units. A boiler incorporates a firebox or furnace in order to burn the fuel and generate heat. The generated heat is transferred to water to make steam. This produces saturated steam at a rate which can vary according to the pressure above the boiling water. The higher the furnace temperature means the faster steam production. The saturated steam thus produced can then either be used immediately to produce power via a turbine and alternator, or else may be further superheated to a higher temperature, this notably reduces suspended water content making a given volume of steam produce more work and creates a greater temperature gradient, which helps reduce the potential to form condensation. Any remaining heat in the combustion gases can then either be evacuated or made to pass through an economizer, the role of which is to warm the feed water before it reaches the boiler [1].

Boilers are used for a variety of purposes in an assortment of applications. Common uses include producing hot water or steam for heating, producing steam for use within a plant such as atomizing oil for oil-fired burners and producing steam to generate power in large power plants. Applications range from small single-burner uses in hospitals, schools, and small businesses up to large multi burner boilers in power plants. The burners used in boilers are typically regulated because of their proliferation and widespread use in applications involving the general public. The source of heat for a boiler is combustion of any of several fuels, such as wood, coal, oil, or natural gas. Electric steam boilers use resistance- or immersion-type heating elements. Nuclear fission is also used as a heat source for generating steam, either directly or, in most cases, in specialized heat exchangers called “steam generators." Heat recovery steam generators use the heat rejected from other processes such as a gas turbine.

Most boilers produce steam to be used at saturation temperature; that is, saturated steam. Superheated steam boilers vaporize the water and then further heat the steam in a superheated. This provides steam at a much higher temperature, but can decrease the overall thermal efficiency of the steam generating plant because the higher steam temperature requires a higher flue gas exhaust temperature. There are several ways to circumvent this problem, typically by providing an economizer that heats the feedwater, a combustion air heater in the hot flue gas exhaust path, or both. There are advantages to superheated steam that may, and often will, increase overall efficiency of both steam generation and its utilization: gains in input temperature to a turbine should outweigh any cost in additional boiler complication and expense. There may also be practical limitations to using wet steam, as entrained condensation droplets will damage turbine blades [1].

Superheated steam presents unique safety concerns because, if any system component fails and allows steam to escape, the high pressure and temperature can cause serious, instantaneous harm to anyone in its path. Since the escaping steam will initially be completely superheated vapor, detection can be difficult, although the intense heat and sound from such a leak clearly indicates its presence. Superheater operation is similar to that of the coils on an air conditioning unit, although for a different purpose. The steam piping is directed through the flue gas path in the boiler furnace. Some superheaters are the radiant type; that is, they absorb heat by radiation. Others are the convection type, absorbing heat from a fluid. Some are a combination of the two types. Through either method, the extreme heat in the flue gas path will also heat the superheater steam piping and the steam within. While the temperature of the steam in the superheater rises, the pressure of the steam does not and the pressure remains the same as that of the boiler. Almost all steam superheater system designs remove droplets entrained in the steam to prevent damage to the turbine balding and associated piping. Steam boilers are being confronted with complex operating processes brought on by deregulation. In order to compete in today's electrical power market place and meet these complex operating conditions. Steam boilers have begun to retrofit their steam turbine control systems with modern control platforms. Because these modern control platforms provide better control of the steam boilers, the flexibility to meet the demands of the market can be obtained. The control system design is critical to optimize availability and reliability while minimizing impact on maintenance and capital budgets. Issues such as boiler performance, controls integration and future upgrades are sometimes overlooked when implementing a boiler control system modification. A practical control problem that has received a great deal of attention lately is the robust control of power plants. It is well known that automatic control is deemed a necessary condition for safe operation which minimizes material fatigue, the number of staff, and enables efficient plant management. However, the design of controllers for power plants is not a trivial task. The challenge in controller design for these plants exists because they are typically non-linear and multivariable with multiple control objectives. While conventional controls such as Proportional Integral Derivative (PID) controller compensators yield an acceptable response, they do not have the flexibility necessary to provide a good performance over a wide region of operation [2].

Literature Review and Related Works Covered:

Since the first boilers, for transforming fossil energy (solid fuels, oil or gas) to the energy carrying medium (water, steam, thermal fluid etc.), were developed at the start of the industrial area, the advanced heat exchangers, as boilers actually are, have been the subject of continuous development aiming at: higher efficiency, lower emission levels, higher availability, better operational performance etc. During this period the development focus has been strongly influenced by such factors as, higher energy costs demanding higher efficiency, environmental attention demanding lower emissions, higher salary levels demanding simpler operation (higher degree of automation) etc.[1]

Several research works recently have discussed the control steam turbine temperature by using different types of control systems. In Japan, where energy costs have traditionally been high, recovery boilers have been built that run superheat cycles with pressures and temperatures as high as 1915 psig (132 bar) and 960 F (515C). In north America there are boilers that have operating conditions of 1550 psig (107 bar) and 925F (496C), but approximately 60% of the recovery boilers in North America operate at or below 900 psig (62 bar). Since the 1960s, electrical generating utilities have operated natural circulation boilers in excess of 2600 psig (180 bars) at the superheater outlet. These utility boilers operate with superheater and reheater temperatures from 1000 to 1055 F (538 to 568C). The reheat cycle greatly improves thermal efficiency of the power generation cycle. Utility boiler experience applied to a pulp mill steam cycle would greatly improve the electrical power generation potential of a pulp mill steam cycle. Babcock and Wilcox Power Generation Group have made developments in the recovery boiler design that will allow a recovery boiler to operate at utility pressures and with reheat steam cycles. This study [3] is about superheat steam temperature control concept in once -through boilers - a review. In once through boilers, superheated steam temperature is controlled by means of coordinated feedwater flow and spray attemperation. For superheat steam temperature control, many methods are being adopted namely burner tilt, gas recirculation, divided back pass dampers, excess air and steam bypass as primary control and feed water attemperation is envisaged as emergency control. When the boiler is operated in sliding pressure mode the cold reheat steam temperature is higher compared to constant pressure operation. The adjustment required for maintaining constant superheat outlet temperature is larger in constant pressure operation mode. In general spray is not used for superheated steam temperature control for boilers designed for constant pressure operation since the spray quantity required will be large and its impact on plant heat rate. In Europe utility boilers are operated under sliding pressure mode and hence superheated steam temperature control by spray is a common practice especially for once-through boilers. This thesis deals with the benefits and losses of superheated steam temperature control in lieu of other control mechanisms .This study [4] about advanced control of Steam superheat temperature on a utility boiler**.** Steam superheat temperature control is critical to the efficient operation of utility boiler steam turbines. Traditional Proportional-Integral Derivative (PID) controllers are difficult to apply in this application due to significant time delay and changing process dynamics as a function of turbine load. This thesis describes the application of a predictive adaptive model based controller (Brain Wave) on a 100 MW Utility Boiler to control steam superheat temperature.

Fuzzy logic represents soft computing method for solving problems where classical logic cannot provide satisfying results. Fuzzy logic is multi-value logic derived from theory of fuzzy sets proposed by L. A. Zadeh (1965). This kind of logic gained success because it makes use of the tolerance for imprecision and uncertainty to achieve tractability, robustness, and low cost solution. The key quality of fuzzy logic standpoint is the possibility of giving a formal and procedural representation of linguistic terms used to state human centered concepts [3].

The concept of intelligent control lies with the fact that human intelligence is imbibed in to the controller architecture so that human behavior can be emulated in the control decision. Human expert knowledge is based upon heuristic information gained in relation to the operation of the plant or process, and its inherent vagueness ("fuzziness") offers a powerful tool for the modeling of complex systems. The fuzzy logic controller provides an algorithm, which converts the expert knowledge into an automatic control strategy. Fuzzy logic is capable of handling approximate information in a systematic way and therefore it is suited for controlling nonlinear systems and is used for modeling complex systems where an inexact model exists or systems where ambiguity or vagueness is common. The fuzzy control systems are rule based systems in which a set of fuzzy rules represent a control decision mechanism to adjust the effects of certain system stimuli. With an effective rule base, the fuzzy control systems can replace a skilled human operator. The rule base reflects the human expert knowledge, expressed as linguistic variables, while the membership functions represent expert interpretation of those variables [4].

1.2 Problem Statement

Boiler is the main component of generating steam in thermal power generation units and its control is very important in many applications. In present situation conventional PID control is being used for this purpose. These conventional controllers in power plants are not very stable when there are fluctuations and, in particular, when there is an emergency occurring. Continuous processes in power plant and power station are complex systems characterized by nonlinearity, uncertainty and load disturbances. The conventional controllers do not work accurately in a system with nonlinearity. Here in Dr.shareef power station there are two new units gives (100 MW), their boilers have open superheat cycle which increasing the overall of temperature which can lead to instability system and loss a lot of fuel that is used in burning. The current method of measuring and controlling the temperature is not accurate and affects the performance of the other components.

1.3 Objectives

The main objectives of this study are to:

- Develop of boiler turbine system model.

- Design of Proportional Integral (PI) controller for boiler turbine system.
- Design of fuzzy logic controller for boiler turbine system.
- Comparison of controller’s response.
- Prediction performance of system based on simulation results.

1.4 Methodology

The proposed method consists of two sections. First section concerns with pressure and power output control and the second section consists of water level control system. For both of the sections fuzzy logic control is designed. The system variables and components are modeled and simulation is done using MATLAB / SIMULINK software.

1.5 Layout

This thesis consists of five chapters including this chapter. Chapter one gives an introduction, problem statement for this study. It also presents the objectives and methodology of this study. Chapter two gives a theoretical background; discuss briefly the basic construction of boiler, then list of classification, fuzzy control system and conventional (PID) controller. Chapter three mainly focuses on the mathematical modeling and simulation of the boiler using MATLAB/SIMULINK. Secondly, the design of PI controller and fuzzy logic controller are described. Chapter four handles the simulation results and discussion. Finally chapter five presents conclusions and recommendations.

CHAPTER TWO

THEORETICAL ACKGROUND

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2.1 Boiler

Boilers are manufactured in many different sizes and configurations depending on the characteristics of the fuel, the specified heating output, and the required emissions controls. Figure 2.1 shows the industrial boiler, some boilers are only capable of producing hot water, while others are designed to produce steam. Combustion boilers are designed to use the chemical energy in fuel to raise the energy content of water so that it can be used for heating and power applications. Many fossil and non-fossil fuels are fired in boilers, but the most common types of fuel include coal, oil, and natural gas. During the combustion process, oxygen reacts with carbon, hydrogen, and other elements in the fuel to produce a flame and hot combustion gases. As these gases are drawn through the boiler, they cool as heat is transferred to water. Eventually the gases flow through a stack and into the atmosphere. As long as fuel and air are both available to continue the combustion process, heat will be generated [5].

Figure 2.1: Industrial boiler

2.1.1 Operation

The separated steam is drawn out from the top section of the drum and distributed for process. Further heating of the saturated steam will make superheated steam normally used to drive a steam turbine. Saturated steam is drawn off the top of the 5 drum and re-enters the furnace in through a superheater. The steam and water mixture enters the steam drum through riser tubes; drum internals consisting of demister separate the water droplets from the steam producing dry steam. The saturated water at the bottom of the steam drum flows down through the downcomer pipe, normally unheated, to headers and water drum. Its accessories include a safety valve, water level indicator and level controller. Feed-water of boiler is also fed to the steam drum through a feed pipe extending inside the drum, along the length of the steam drum. A steam drum is used without or in the company of a mud-drum/feed water drum which is located at a lower level. A boiler with both steam drum and mud/water drum is called a bi-drum boiler and a boiler with only a steam drum is called a mono-drum boiler. The bi-drum boiler construction is normally intended for low pressure-rating boiler while the mono-drum is mostly designed for higher pressure-rating [6].

2.1.2 Boiler types

Boilers can be classified in many types:

i. Horizontal, vertical or inclined

   If the axis of the boiler is horizontal, vertical or inclined then it is called horizontal, vertical or inclined boiler respectively.

ii. Fire tube and water tube

   If hot gases are inside the tube and water is outside the tube, it is called fire tube boiler as shown in Figure 2.2. Examples: Cochran, Lancashire and locomotive boilers. If water is inside the tube and hot gases are outside the tube, it is called water-tube boiler as shown in Figure 2.3. Examples: Babcock and Wilcox, Sterling, Yarrow boiler etc.

iii. Externally fired and internally fired

The boiler is known as externally fired if the fire is outside the shell. Examples: Babcock and Wilcox, Sterling the boiler is known as internally fired if the furnace is located inside the boiler shell. Examples: Cochran, Lancashire.

iv. Forced circulation and natural circulation

In forced circulation type of boilers, the circulation of water is done by a forced pump. Examples: Velox, Lamont, Benson boiler. In natural circulation 6 type of boilers, circulation of water in the boiler takes place due to natural convection currents produced by the application of heat. Examples: Lancashire, Babcock and Wilcox.

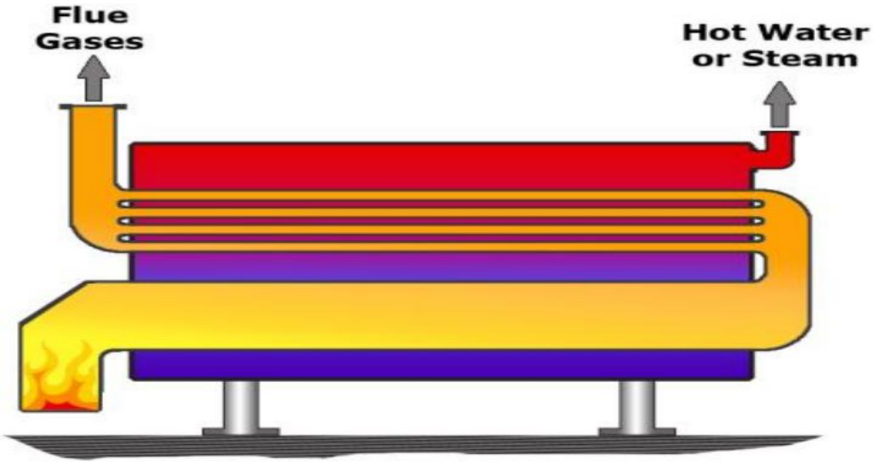

Figure 2.2: Fire tube boiler

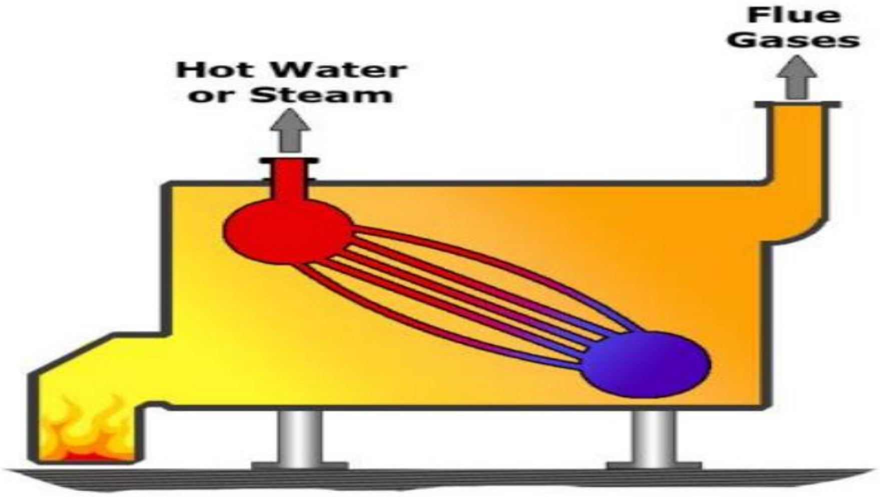

Figure 2.3: Water tube boiler

v. High pressure and low pressure

The boilers which produce steam at pressures of 80 bars and above are called high pressure boilers. Examples: Babcock and Wilcox, Velox, Lamont, Benson boilers. The boilers which produce steam at pressure below 80 bars are called low pressure boilers. Examples: Cochran, Cornish, Lancashire and locomotive boilers.

vi. Stationary and portable (moving)

Stationary boilers are used for power plant-steam, for central station utility power plants, for plant process steam etc. Mobile or portable boilers include locomotive type, and other small unit for temporary use at sites.

vii. Single tube and multi tube

The fire tube boilers are classified as single tube or multi-tube boilers, depending upon whether the fire tube is one or more than one. Examples of single tube boilers are Cornish and simple vertical boiler [5].

2.1.3 Boiler circulation

Boilers generate steam using different methods to circulate the steam-water mixture is inside the tubes and is heated by external combustion flames and flue gases. The water tube boilers are classified by the way of the water/steam circulation:

i. Natural circulation

The natural circulation is one of the oldest principles for steam/water circulation in boilers. Its use has decreased during the last decades due to technology advances in other circulation types. Natural circulation principle is usually implemented on small and medium sized boilers. Typically the pressure drop for a natural circulation boiler is about 5-10 % of the steam pressure in the steam drum and the maximum steam temperature varies from 540 to 560 °C.

ii. Assisted or forced circulation

In contrast to natural circulation boilers, forced circulation is based on pump assisted internal water/steam circulation. The circulation pump is the main difference between natural and forced circulation boilers. In the most common forced circulation boiler type, the Lamont boiler, the principles of forced circulation is basically the same as for natural circulation, except for the circulation pump. The operation pressure level of forced circulation boiler can be slightly higher than a natural circulation boiler, but since the steam/water separation in the steam drum is based on the density difference between steam and water, these boilers are not either suitable for supercritical pressures (>221 bar). Practically the maximum operation pressure for a forced circulation boiler is 190 bar and the pressure drop in the boiler is about 2-3 bar.

iii. Once-through

A once-through (or universal pressure) boiler can be simplified as long, externally heated tube. There is no internal circulation in the boiler, thus the circulation ratio for once-through boilers is 1. In contrast to other water tube boiler types (natural and controlled circulation), once through boilers do not have a steam drum. Thus, the length of the evaporator part (where saturated water boils into steam) is not fixed for once through boilers. Once-through boilers are also called universal pressure boilers because they are applicable for all pressures and temperatures. However, once through boilers are usually large sized boilers with high subcritical or supercritical steam pressure. A large modern power plant unit (about 900MW/h) based on the once-through design can be over 160m high with a furnace height of 100m.

iv. Combined circulation

This boiler type is a combination of controlled circulation boilers and once through boilers. Combined circulation (once-through with super imposed recirculation) boilers can be used for both subcritical and supercritical steam pressure operation. When the firing rate is between 60 and 100%, the boiler operates as a once through boiler. At lower than 60% capacity load, combined circulation boilers operate as forced circulation boilers in idea to maintain adequate water/steam flow in wall tubes. The biggest advantage of combined circulation type boilers is reduced demand of pump energy because the operation mode changes depending on the capacity load. Main disadvantages are the troublesome co-operation between feed water pump and circulation pump and also the high level needed for water treatment (as needed for once through boilers) [5].

2.1.4 Material of boiler

The pressure vessel in a boiler is usually made of steel or alloy steel, or historically of wrought iron. Stainless steel is virtually prohibited by American Society of Mechanical Engineers (ASME) boiler code for use in wetted parts of modern boilers, but is used often in super heater sections that will not be exposed to liquid boiler water. In live steam models, copper or brass is often used because it is more easily fabricated in smaller size boilers. Historically, copper was often used for fireboxes particularly for steam locomotives, because of its better formability and higher thermal conductivity, however, in more recent times, the high price of copper often makes this an uneconomic choice and cheaper substitutes such as steel are used instead. For much of the Victorian age of steam, the only material used for boiler making was the highest grade of wrought iron, with assembly by riveting. This iron was often obtained from specialist ironworks, such as at Celator Moor, noted for the high quality of their rolled plate and its suitability for high reliability use in critical applications, such as high pressure boilers. In the 20th century, design practice instead moved towards the use of steel, which is stronger and cheaper, with welded construction, which is quicker and requires less labour. Cast iron may be used for the heating vessel of domestic water heaters. Although such heaters are usually termed boilers, their purpose is usually to produce hot water, not steam, and so they run at low pressure and try to avoid actual boiling [7].

2.1.5 Fuel for boiler

The source of heat for a boiler is combustion of any of several fuels, such as wood, coal, oil, or natural gas. Electric steam boilers use resistance or immersion type heating elements. Nuclear fission is also used as a heat source for generating steam. Heat recovery steam generators use the heat rejected from other processes such as gas turbines [7].

2.1.6 Boiler control

A steam boiler is a complex system consists of numerous components. The pressure variation phenomena inside a furnace of a steam boiler affect the steam boilers efficiency and safety. A boiler is an enclosed vessel that provides a means for converting water into steam. The steam under pressure is then used for transferring the heat to a process. Water is a useful and cheap medium for transferring heat to a process. When water is boiled its volume increases by about 1600 times, producing a force that is almost as explosive as gunpowder. This causes the boiler to be extremely dangerous and must be treated with a lot of care. The boiler's operating conditions is very necessary to control because the high pressures and temperatures are the main hazard problems and it has the risk of explosion. Also steam boiler has very high manufacturing cost, operating cost and maintenance cost. The operating conditions of steam boiler are very complex to control because all the variables (pressure, temperature, flow, level) are interrelated. Taking measurement directly on boiler is very difficult due to dangers from the operating conditions and not economical [8].

2.1.7 Boiler applications

Boilers have many applications in the industries, research and development, etc. Some are listed below:

- They can be used in stationary applications to provide heat, hot water, or steam for domestic use, or in generators.
- They can be used in mobile applications to provide steam for locomotion in applications such as trains, ships, and boats.
- Using a boiler is a way to transfer stored energy from the fuel source to the water in the boiler, and then finally to the point of end use.
- Some steam boats, particularly smaller types such as river launches, were designed around a vertical boiler.
- The Sentinel Waggon works also produced a range of road lorries also known as steam wagons, based on their high-pressure vertical boilers [9].

2.2 Proportional-Integral-Derivative Controllers

The PID controller is the most common form of feedback. It was an essential element of early governors and it became the standard tool when process control emerged in the 1940s. In process control today, more than 95% of the control loops are of PID type, most loops are actually PI control. PID controllers are the largest number of controllers found in industries sufficient for solving many control problems [10].

There are stand-alone systems in boxes for one or a few loops, which are manufactured by the hundred thousand yearly. PID control is an important ingredient of a distributed control system. The controllers are also embedded in many special purpose control systems. PID control is often combined with logic, sequential functions, selectors, and simple function blocks to build the complicated automation systems used for energy production, transportation, and manufacturing. Many sophisticated control strategies, such as model predictive control, are also organized hierarchically. PID control is used at the lowest level; the multivariable controller gives the set points to the controllers at the lower level [11].

PID controllers have survived many changes in technology, from mechanics and pneumatics to microprocessors via electronic tubes, transistors, integrated circuits. The microprocessor has had a dramatic influence on the PID controller. Practically all PID controllers made today are based on microprocessors. This has given opportunities to provide additional features like automatic tuning, gain scheduling, and continuous adaptation [11].

2.2.1 The three-term controller

The transfer function of the PID controller looks like the following:

$$k_p + \frac{ki}{s} + k_d s = \frac{kds^2 + kps + ki}{s} \qquad (2.1)$$

Where

- k_p = Proportional gain.
- k_i = Integral gain.
- k_d = Derivative gain.

First, let's take a look at how the PID controller works in a closed-loop system using the schematic shown in Figure 2.4. The variable Error (e) represents the tracking error, the difference between the desired input value (R) and the actual output (Y). This error signal (e) will be sent to the PID controller, and the controller computes both the derivative and the integral of this error signal. The signal (u) just past the controller is now equal to the proportional gain (k_p) times the magnitude of the error plus the integral gain (k_i) times the integral of the error plus the derivative gain (k_d) times the derivative of the error.

$$u = kpe + ki \int e \, \mathrm{dt} + \mathrm{k_d} \frac{\mathrm{de}}{\mathrm{dt}} \tag{2.2}$$

This signal (u) will be sent to the plant, and the new output (Y) will be obtained. This new output (Y) will be sent back to the sensor again to find the new error signal (e). The controller takes this new error signal and computes its derivative and it's integral again. This process goes on and on [12].

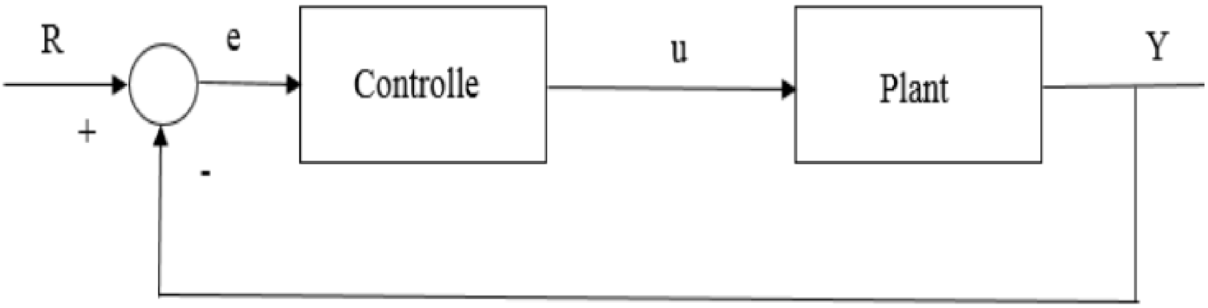

Figure 2.4: Unity feedback system.

2.2.2 The characteristics of PID controllers

A proportional controller (k_p) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error. An integral control (k_i) will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control (k_d) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Effects of each of controllers k_p, k_d, and k_i on a closed-loop system are summarized in the Table 2.1. Note that these correlations may not be exactly accurate, because k_p, k_i, and k_d are dependent of each other. In fact, changing one of these variables can change the effect of the other two. For this reason, the table should only be used as a reference when you are determining the values for k_i, k_p and k_d [12].

Table 2.1: PID controller characteristics parameters

Close Loop Response	Rise Time	Overshoot	Settling Time	Steady State Error
k_p	Decrease	Increase	Small change	Decrease
k_i	Decrease	Increase	Increase	Eliminate
k_d	Small change	Decrease	Decrease	Small change

2.2.3 PID tuning

Tuning the PID controller is the adjustment of its control parameters (k_p, k_i and k_d) to the optimum values for the desired control response. The PID tuning is a difficult problem, even though there are only three parameters and in principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control. There are accordingly various methods for loop tuning, the some traditional manual methods for loop tuning, are presented below:

i. Manual tuning

If the system must remain online, one tuning method is to first set k_i and k_d values to zero. Increase the k_p until the output of the loop oscillates, then the k_p should be set to approximately half of that value for a "quarter amplitude decay" type response. Then increase k_i until any offset is corrected in sufficient time for the process. However, too much k_i will cause instability. Finally, increase k_d, if required, until the loop is acceptably quick to reach its reference after a load disturbance. However, too much k_d will cause excessive response and overshoot. A fast PID loop tuning usually overshoots slightly to reach the set point more quickly; however, some systems cannot accept overshoot, in which case an over-damped closed-loop system is required, which will require a k_p setting significantly less than half that of the k_p setting that was causing oscillation.

ii. Ziegler–Nichols method

Another heuristic tuning method is formally known as the Ziegler–Nichols method, introduced by John G. Ziegler and Nathaniel B. Nichols in the 1940s. As in the method above, the k_i and k_d gains are first set to zero. The proportional gain is increased until it reaches the ultimate gain, k_u, at which the output of the loop starts to oscillate. k_u and the oscillation period T_u are used to set the gains as shown in Table 2.2.

Table 2.2: Ziegler–Nichols method

Control type	k_P	k_i	k_d
P	0.5ku	-	-
PI	0.45ku	0.54ku/Tu	-
PID	0.6ku	1.2ku/Tu	3kuTu /40

iii. PID tuning software

Most modern industrial facilities no longer tune loops using the manual calculation methods shown above. Instead, PID tuning and loop optimization software are used to ensure consistent results. These software packages will gather the data, develop process models, and suggest optimal tuning. Some software packages can even develop tuning by gathering data from reference changes [12].

2.3 Fuzzy Logic

Fuzzy logic is extension of Boolean logic. It incorporates partial values of truth. Instead of sentences being completely true or completely false, here in fuzzy logic they are assigned a value which represents their degree of truthiness. In fuzzy systems, values are indicated by a number called as truth value. It lies in the range from 0.0 to 1.0 represents absolute falseness and 1.0 represents absolute truth. Fuzzification is generalization of theory from discrete to continuous. Fuzzy logic is important to artificial intelligence. Fuzzy logic allows computers to answer to a certain degree unlike Boolean logic which gives one extreme or the other. Computers are allowed to think more humanlike. Nothing in our perception is extreme. However, it is true only to a certain degree. In fuzzy logic, machines think in degrees. It can solve problems in the cases where there is no simple mathematical model. Fuzzy logic solves highly nonlinear processes. Fuzzy logic uses expert knowledge to make decisions [13].

Fuzzy logic was first invented as a representation scheme. It acts as calculus for uncertain or vague notions. It allows more human-like interpretations. Fuzzy logic has put reasoning in machines by resolving intermediate categories between notations like true/false, hot/cold etc. Fuzzy logic is a problem-solving control system methodology. It lends itself to implementation in systems ranging from small, simple, embedded microcontrollers to large, multi-channel, networked Personal Computer (PC) or workstation-based data acquisition control systems etc. It can be implemented in software, hardware, or a combination of both. Fuzzy logic provides a simple way to arrive at a definite conclusion. Conclusion is based upon ambiguous or vague, noisy, imprecise, or missing input information. Fuzzy logic's approach to control problems simply mimics how a person will make efficient decisions much faster [13].

In 1965, professor L.A.Zadeh of the University of California, Berkely presented his paper outlining fuzzy theory in which he introduced the concept of fuzzy set theory and operation, fuzzy logic based controller etc. In about 1970, fuzzy logic theory began to produce result in Japan, Europe and China. In the year 1987, 16 station subway railway systems were built which worked with a fuzzy logic-based automatic train operation control system in Sendai, Japan. The ride is so smooth that the riders do not need to hold straps, and the controller makes seventy percent fewer judgmental errors in acceleration and braking than human operators do. Fuzzy logic is a powerful problem-solving methodology with a myriad of applications in embedded control and information processing. Fuzzy provides a remarkably simple way to draw definite conclusions from vague, ambiguous or imprecise information. In a sense, fuzzy logic resembles human decision making with its ability to work from approximate data and find precise solutions. Unlike classical logic, which requires a deep understanding of a system, exact equations, and precise numeric values, fuzzy logic incorporates an alternative way of thinking, which allows modeling complex systems using a higher level of abstraction originating from our knowledge and experience. Fuzzy logic allows expressing this knowledge with subjective concepts such as very hot, bright red, and a long time, which is mapped into exact numeric, ranges [14].

Fuzzy logic is a paradigm for an alternative design methodology, which can be applied in developing both linear and non-linear systems for embedded control. Fuzzy logic provides an alternative solution to non-linear control because it is closer to the real world. Rules, membership functions, and the inference process which results in improved performance, simpler implementation, and reduced design costs handle non-linearity. By using fuzzy logic, designers can realize lower development costs, superior features, and better end product performance. Furthermore, products can be brought to market faster and more cost-effectively. Fuzzy logic has been gaining increasing acceptance during the past few years. There are over two thousand commercially available products using fuzzy logic, ranging from washing machines to high-current trains. Nearly every application can potentially realize the benefits of fuzzy logic [15].

2.3.1 Fuzzy logic features

Fuzzy logic offers several unique features that make it a particularly good choice for many control problems.

- It is inherently robust since it does not require precise, noise-free inputs and can be programmed to fail safely if a feedback sensor quits or is destroyed. The output control is a smooth control function despite a wide range of input variations.
- Since the fuzzy logic controller processes user-defined rules governing the target control system, it can be modified and tweaked easily to improve or drastically alter system performance. New sensors can easily be incorporated into the system simply by generating appropriate governing rules.
- Fuzzy logic is not limited to a few feedback inputs and one or two control outputs, nor is it necessary to measure or compute rate-of-change parameters in order for it to be implemented. Any sensor data that provides some indication of a system's actions and reactions is sufficient. This allows the sensors to be inexpensive and imprecise thus keeping the overall system cost and complexity low.
- Because of the rule-based operation, any reasonable number of inputs can be processed and numerous outputs generated, although defining the rule

base quickly becomes complex if too many inputs and outputs are chosen for a single implementation since rules defining their interrelations must also be defined. It would be better to break the control system into smaller chunks and use several smaller fuzzy logic controllers distributed on the system, each with more limited responsibilities.

- Fuzzy logic can control nonlinear systems that would be difficult or impossible to model mathematically [15].

2.3.2 The designing of fuzzy logic:

- Define the control objectives and criteria: What am I trying to control? What do I have to do to control the system? What kind of response do I need? What are the possible system failure modes?
- Determine the input and output relationships and choose a minimum number of variables for input to the fuzzy logic engine, typically that are error and rate of change of error.
- Using the rule-based structure of fuzzy logic, break the control problem down into a series of IF X AND Y THEN Z rules that define the desired system output response for given system input conditions. The number and complexity of rules depends on the number of input parameters that are to be processed and the number fuzzy variables associated with each parameter. If possible, use at least one variable and its time derivative. Although it is possible to use a single, instantaneous error parameter without knowing its rate of change, this cripples the system's ability to minimize overshoot for a step inputs.
- Create fuzzy logic membership functions that define the meaning or values of input/output terms used in the rules.
- Test the system, evaluate the results, tune the rules and membership functions, and retest until satisfactory results are obtained [15].

2.3.3 Operations

Fuzzy logic requires some numerical parameters in order to operate such as what is considered significant error and significant rate of change of error, but exact values of these numbers are usually not critical unless very responsive performance is required in which case empirical tuning would determine them [16].

2.3.4 Fuzzy logic types

These two types of fuzzy sets are explained in the following sections:

A. Type I fuzzy set

Lets‘X be a collection of objects called universe of discourse. A fuzzy set A ∈ X is characterized by membership function μA(X) which represents the degree of membership. Degree of membership maps each element between 0 and 1. It is defined as:

$A = \{(x, \mu A(X)); x \in X\}$ (2.3)

Figure 2.5 shows the triangular membership function with three linguistic variables as small, medium and large. For X = 18.75, degree of membership for small is 0.6 and degree of membership for medium is 0.4.

B. Type II fuzzy set

The type-2 fuzzy set model makes use of an extra third dimension. These sets are typically implemented as points stored in an array. Type-2 fuzzy logic requires two different levels of discretization: for the primary and secondary membership functions. In the case of generalized type-2 membership functions, where the secondary is a type-1 fuzzy number, the computational complexity is very large [16].

2.3.5 Fuzzy inference system

Fuzzy Inference Systems (FIS) are rule-based systems. It is based on fuzzy set theory and fuzzy logic. FIS are mappings from an input space to an output space. FIS allows constructing structures which are used to generate responses or outputs for certain stimulations or inputs. Response of FIS is based on stored knowledge or relationships between responses and stimulations. Knowledge is stored in the form of a rule base. Rule base is a set of rules. Rule base expresses relations between inputs of system and its expected outputs [12].

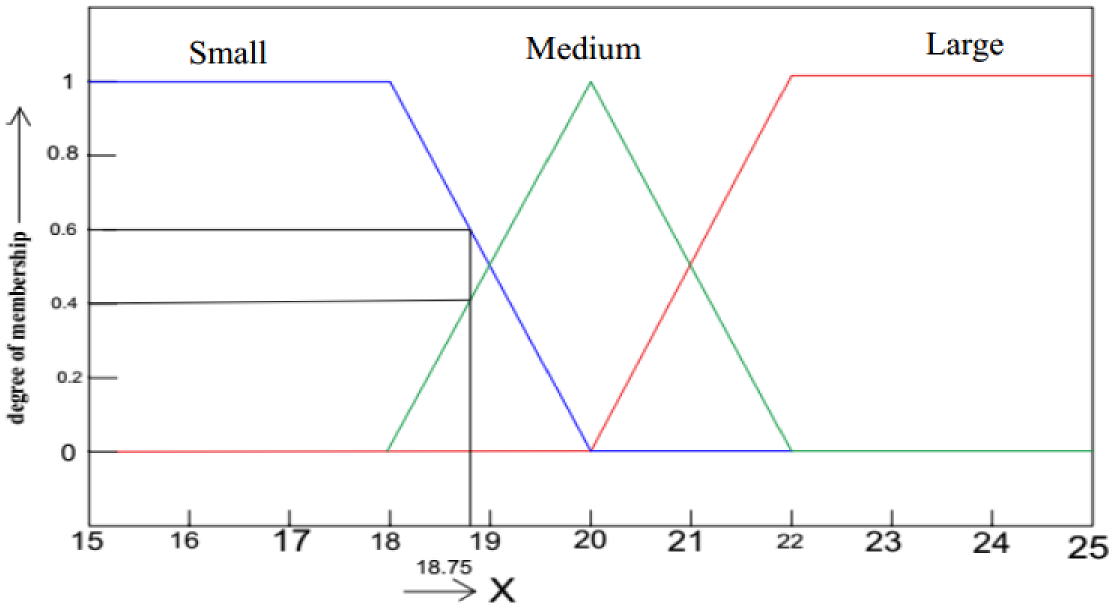

Figure 2.5: Fuzzy logic membership function

Knowledge is obtained by eliciting information from specialists. These systems are usually known as fuzzy expert systems. Another common denomination for FIS is fuzzy knowledge-based systems. It is also called as data-driven fuzzy systems. FIS are usually divided in two categories viz. Multiple Input and Multiple Output (MIMO) systems and Multiple Input and Single Output (MISO) systems, the system returns several outputs based on the inputs which it receives. Multiple input and single output systems are those where only one output is returned from multiple inputs. MIMO systems are decomposed into a set of MISO systems which work in parallel. Figure 2.6 shows the block diagram of fuzzy logic system. It has different blocks: fuzzifier, knowledge base, inference unit and defuzzifier.

In terms of inference process there are two main classes of FIS:

A. Mamdani based FIS

In mamdani based fuzzy inference system, inputs and outputs have an If-Then rules. A typical rule in a mamdani fuzzy model is: IF X is Negative Big AND Y is Negative Small THEN Z is Zero.

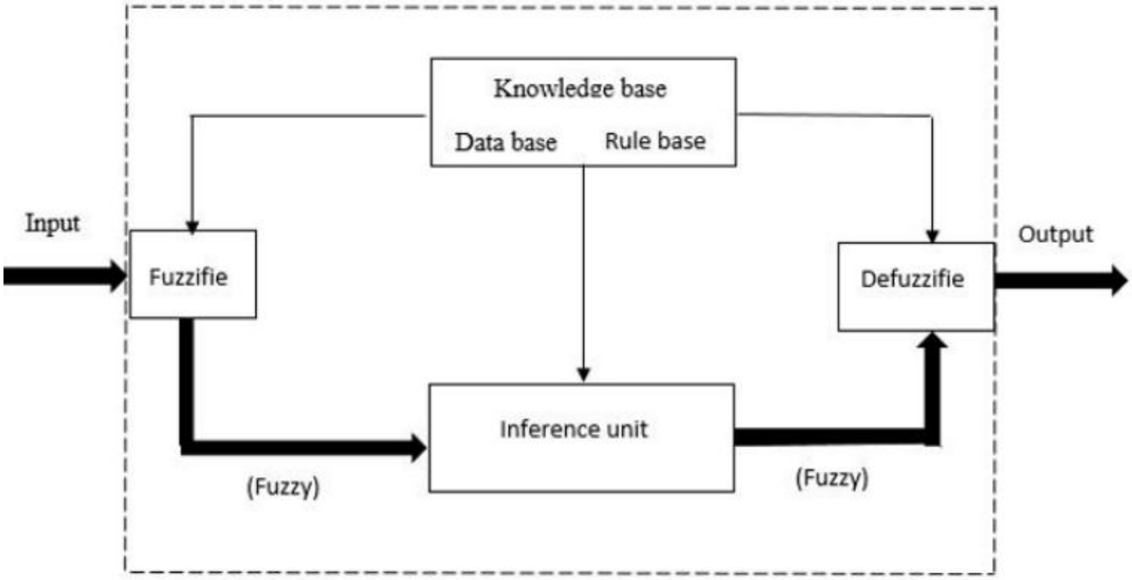

Figure 2.6: Block diagram of fuzzy logic system

B. Sugeno based FIS

Sugeno-type systems are used to model any inference system in which output membership functions are either linear or constant. This fuzzy inference system was introduced in 1985. It is also called as Takagi-Sugeno-Kang. Sugeno output membership functions (z) are either linear or constant. A typical rule in a Sugeno fuzzy model is:

If Input 1 = x and Input 2 = y, then Output is $z = ax + by + c$.

For a zero-order Sugeno model, the output level z is a constant ($a=b=0$). Figure 2.7 shows the rule viewer of the fuzzy logic system in case of mamdani inference system. The rule viewer shows one calculation at a time and in great detail.

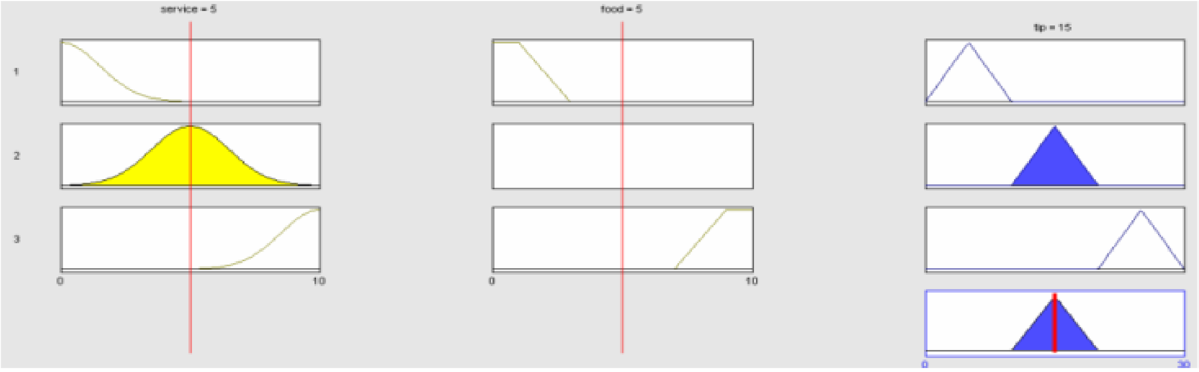

Figure 2.7: Fuzzy rule base in the case of a mamdani fuzzy inference system

Both sugeno and mamdani FIS can be used to perform the similar tasks. Rule base and fuzzification remain same for the variables. There are various defuzzifiers that can be chosen for a mamdani FIS. These defuzzifiers also originate similar results in a sugeno FIS. There is a certain overlap between both types of systems. Mamdani FIS is more widely used. It is used for decision support applications, because of its intuitive and interpretable nature. Consequences of the rules in a sugeno FIS do not have a direct semantic mean. This means that they are not linguistic terms. Also, this interpretability is partially lost. Sugeno FIS rules consequents can have many parameters per rule as per input values. Thus, sugeno FIS gets translated into more degrees of freedom in its design as compared to mamdani FIS. Thus it provides more flexibility. Many parameters can be used in the consequents of the rules of a sugeno FIS. A zero order sugeno FIS can reasonably approximate a mamdani FIS. In computational terms, a sugeno FIS is more efficient than a mamdani FIS. It is so because, sugeno FIS does not involve computationally expensive defuzzification process. Also, a sugeno FIS always generates continuous surfaces. The continuity of the output surface is quite important. Any existence of discontinuities will result in similar inputs originating substantially different outputs. It will be a situation which is undesirable from the control monitoring perspective. Because of continuous structure of output functions, a sugeno FIS is also better and adequate for functional analysis than a mamdani FIS. Figure 2.8

shows the surface view of the fuzzy logic system in case of mamdani inference system. It is very helpful in case of two or more inputs and one output [16].

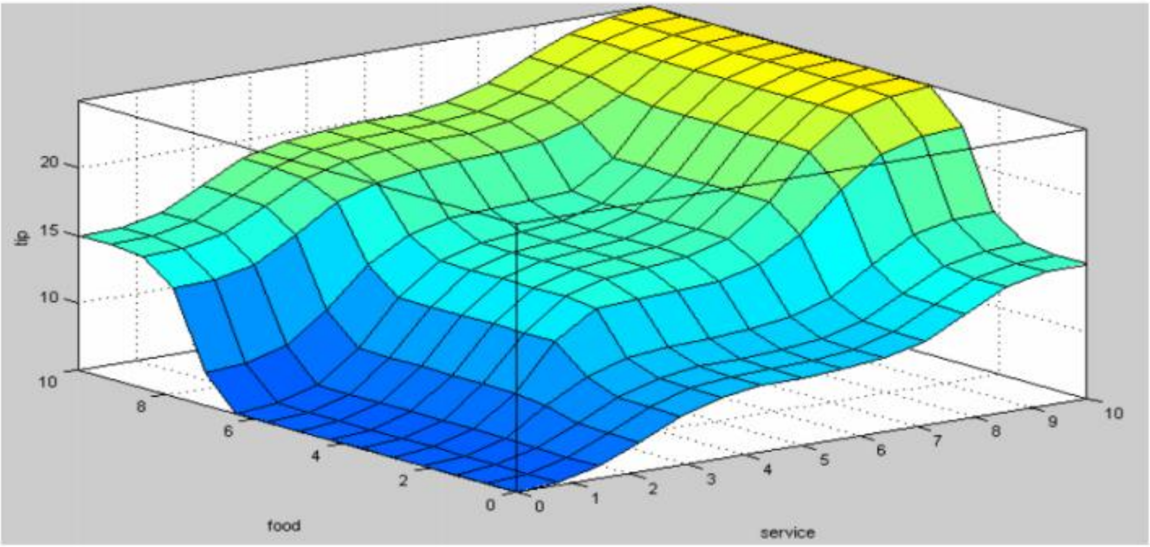

Figure 2.8: Surface view in the case of a mamdani fuzzy inference system

2.3.6 Defuzzification

Defuzzification converts the fuzzy outputs back to crisp values. There are different defuzzification methods given as:

- Max ember ship.
- Centroid.
- Bisector.
- Weighted average.
- Mean-max.
- Center of sum.

2.3.7 Control scheme

This section describes the classical control scheme and fuzzy control scheme. In classical control scheme we have open loop and closed loop control architecture. Figure 2.9 shows the classical feedback control structure of a plant. In fuzzy control scheme the conventional controller is replaced by fuzzy logic controller. The fuzzy control scheme is shown in Figure 2.10

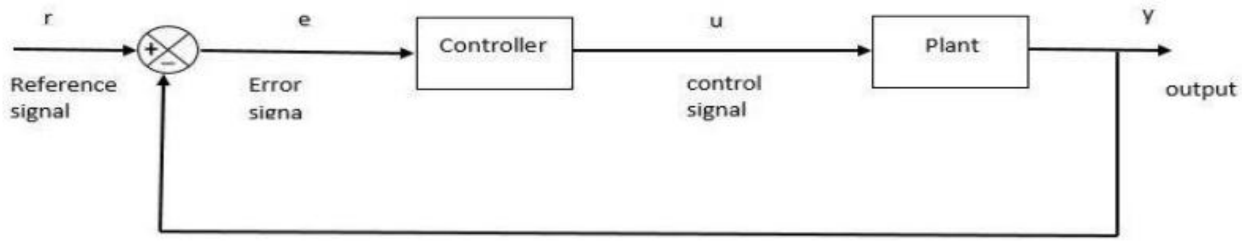

Figure 2.9: Classical feedback control scheme

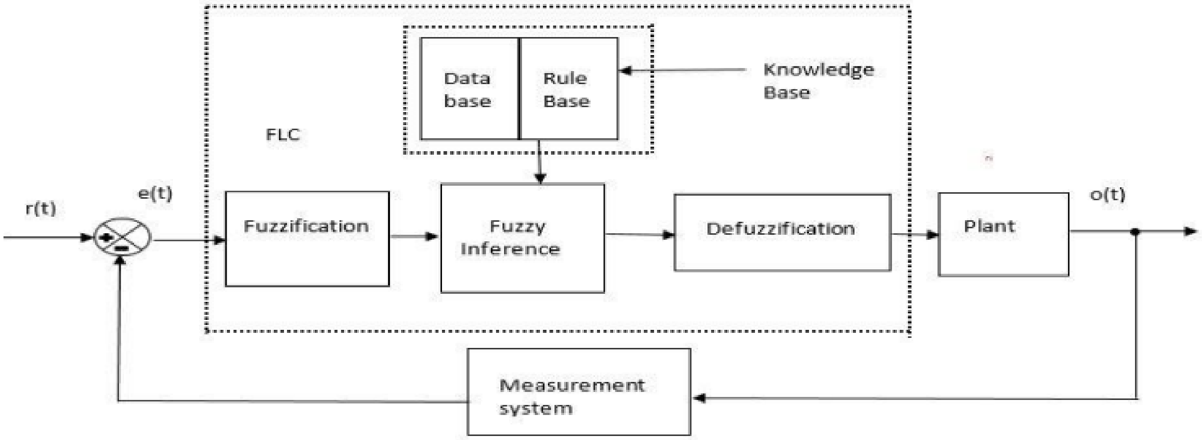

Figure 2.10: Fuzzy logic control scheme

The majority of fuzzy logic control systems are knowledge-based systems in that either their fuzzy models or their fuzzy logic controllers are described by fuzzy IFTHEN rules, which have to be established based on experts' knowledge about the systems, controllers, performance, etc. Moreover, the introduction of input-output intervals and membership functions is more or less subjective, depending on the designer's experience and the available information. However, we emphasize once again that after the determination of the fuzzy sets, all mathematics to follow are rigorous. Also, the purpose of designing and applying fuzzy logic control systems is, above all, to tackle those vague, ill-described, and complex plants and processes that can hardly be handled by classical systems theory, classical control techniques, and classical two-valued logic. This is the first type of fuzzy logic control system: the fuzzy logic controller directly performs the control actions and thus completely replaces a conventional control algorithm. Yet, there is another type of fuzzy logic control system: the fuzzy logic controller is involved in a conventional control system and thus becomes part of the mixed control algorithm, so far as to enhance or improve the performance of the overall control system. The fuzzy logic controller provides an algorithm, which converts the expert knowledge into an automatic control strategy. Fuzzy logic is capable of handling approximate information in a systematic way and therefore it is suited for controlling nonlinear systems and is used for modeling complex systems, where an inexact model exists or systems where ambiguity or vagueness is common. The fuzzy control systems are rule based systems in which a set of fuzzy rules represent a control decision mechanism for adjusting the effects of certain system stimuli. With an effective rule base, the fuzzy control systems can replace a skilled human operator. The rule base reflects the human expert knowledge, expressed as linguistic variables, while the membership functions represent expert interpretation of those variables. Designing a good fuzzy rule base is the key to obtain satisfactory control performance for a particular operation. Classical analysis and control strategy are incorporated in the rule base. The control literature has worked towards reducing the size of the rule base and optimizing the rule base using different optimization techniques like Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) for intelligent controller. At last defuzzified output is obtained from the fuzzy inputs [16].

2.3.8 Fuzzy applications

In the decade after Dr.Zadeh’s seminal paper on fuzzy sets many theoretical developments in fuzzy logic took place in the United States, Europe, and Japan. From the mid-seventies to the present, however, Japanese researchers have been a primary force in advancing the practical implementation of the theory; they have done an excellent job of commercializing this technology. Fuzzy logic affects many disciplines. In video graph, for instance, Fisher, Sanyo, and others make fuzzy logic camcorders, which offer fuzzy focusing and image stabilization. Mitsubishi manufactures a fuzzy air conditioner that controls temperature changes according to human comfort indexes. Matsushita builds a fuzzy washing machine that combines smart sensors with fuzzy logic. The sensors detect the color and kind of clothes present and the quantity of grit, and a fuzzy microprocessor selects the most appropriate combination from 600 available combinations for water temperature, detergent amount and washes and spins cycle times. The Japanese city of Sendai has a 16-station subway system that is controlled by a fuzzy computer. The ride is so smooth that the riders do not need to hold straps, and the controller makes 70 percent fewer judgmental errors in acceleration and braking than human operators do. Nissan introduced a fuzzy automatic transmission and a fuzzy anti-skid braking system in one of their recent luxury cars. Tokyo’s stock market has stock-trading portfolios based on fuzzy logic that outperformed the Nikkei exchange average. In Japan, there are fuzzy golf diagnostic systems, fuzzy toasters, fuzzy rice cookers, fuzzy vacuum cleaners, and many other industrial fuzzy control processes.

With increasing complexities in system engineering, the focus of fuzzy control is moving from elementary control problems to higher levels in the system hierarchy such as supervisory control, monitoring and diagnosis, and logistic support. It is to be noted that telecommunications, which is one of the major future industries, has started investigating fuzzy control for communication systems and that several pilot projects have been initiated for tackling routing and overload handling problems. So far, the majority of existing applications are purely software-based. However, general purpose fuzzy logic processors or coprocessors will be found to be useful in extremely time critical applications like pattern recognition task in complex plant automation and in mass produced automotive electronics. The first generation of fuzzy control in the existing applications exploits only a very small fragment of fuzzy logic theory. In many cases of more complex, ill-structured problems, this first generation technology is not sufficiently equipped to represent and implement the knowledge needed for powerful solutions. Besides, there is strong need for a more systematic design and analysis methodology for fuzzy control applications, spanning the whole life-cycle from perception to all the way up to deployment and maintenance. It must provide answers to make a proper choice of alternative design issues after a thorough analysis of the problem, and must be able to associate variations of parameters to system-performance. At this stage, one should not expect a universal design and optimization strategy for fuzzy control, which will be of some practical use. Such a universal theory does not exist for conventional control engineering either. Instead, we have to proceed from the few isolated islands where we already know exactly how to design a fuzzy control algorithm to clusters of problems and related design methodologies. From the above discussions it is apparent that fuzzy control has tremendous scope in the knowledge based systems approach to closed loop control system, which may be defined as: A knowledge based system for closed loop control is a system which enhances the performance, reliability and robustness of control by incorporating knowledge which cannot be captured in the analytical model used for controller design and that is taken care of by manual modes of operation or by other safety and ancillary logic mechanism [17].

CHAPTER THREE

SYSTEM MODELING AND CONTROL DESIGN

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3.1 Mathematical Modeling

A mathematical model is developed to describe the dynamics of the boiler drum of a natural circulation boiler. A boiler drum is divided into two parts; the upper part contains saturated steam while the lower part contains a steam/water mixture. Balance equations are applied to the drum. The resulting equations are used to model the drum-level. The importance of the resulting model comes from the direct modeling of boiler which is usually computed off-line with the aid of empirical formulas and assumptions. The development of a mathematical model for drum type boilers requires a combination of non-linear equations, modeling water level is a quite complicated task because of the complex flow patterns inside the drum. Although the drum level is very important parameter to control for safe operation of boilers, none of the available literature presents a complete model for the system including the drum level [18].

3.1.1 Model formulation

Figure 3.1 shows a schematic diagram of natural circulation drum type boiler. The heat released from the combustion of fuel is used to evaporate water in the riser tubes. The resulting difference in water densities causes the circulating flow of water. Accordingly, the water-steam mixture enters the lower part of the drum. Steam flows out at the top of the drum as demanded. Feed-water makeup is supplied to the lower part of the drum. Modeling of the boiler includes the essential inputs and outputs needed for the overall plant operation and control. In the system the variable, fuel flow, feedwater flow, two actuator flows and the control valve position were considered as input. The recorded outputs were drum pressure, generated electric power, drum level and pressure in various parts of the system [19].

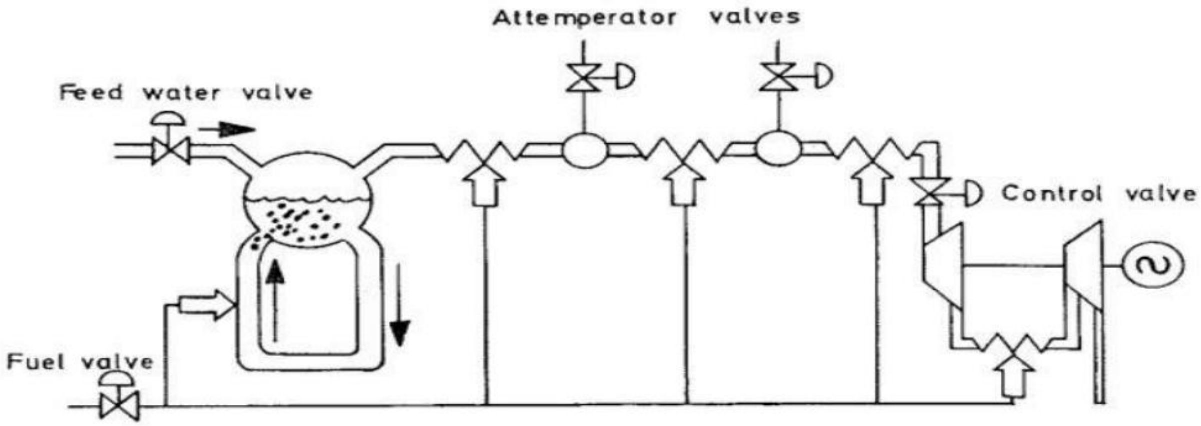


Figure 3.1: The boiler drum

The basic equations used from the Astrom and Eklund work are:

$$\frac{dP}{dt} = -0.0018u_2P^{9/8} + 0.02u_1 - 4.4 \times 10^{-4}u_3 \quad (3.1)$$

$$P_0 = 0.6u_2\, p^{9/8} \quad (3.2)$$

Where u_1 and u_3 are the fuel and feedwater flows in T/hr respectively. u_2 is the control valve position. P and P0 are the output variables of drum pressure and electrical output. This work was extended by Bell and Astrom (1979) and resulted in the following model:

$$\frac{dP}{dt} = -0.0018u_2P^{9/8}+0.9u_1-0.15u_3 \quad (3.3)$$

$$\frac{dP0}{dt} = \{(0.73u_2 + 0.16)P^{9/8} - P_0\}/10 \quad (3.4)$$

Where: u_1 and u_3 are the fuel and feedwater actuator positions, u_2 is the control valve position.

P and P_0 are the drum pressure and electrical output. Note that the differences between the model in Equations. (3.3) and (3.4), and that in (3.1) and (3.2) are:

- The fuel and feedwater flows have been changed to actuator positions, so that all controls are of the same type.

- A differential equation has been used instead of the algebraic equation for the electrical output. This is to include the time lag associated with the steam capacity and inertia of the turbine and alternator.

- An extra constant (0.16) has been included in Equation (3.4) to allow for the heat energy passing to the condensers and feed heaters. A further extension by Bell and Astrom (1979) included equations for predicting drum water level. This model had two forms, the simplest being:

$$\frac{dP}{dt} = -0.0018u_2P^{9/8}+0.9u_1-0.15u_3 \qquad (3.5)$$

$$\frac{dP0}{dt} = \{(0.73u_2+0.16)P^{9/8}-P_0\}/10 \qquad (3.6)$$

$$W_s = (1.1u_2-0.19)P \qquad (3.7)$$

$$\frac{d\rho f}{dt} = \frac{141u3-\mathrm{Ws}}{\mathrm{Vt}} \qquad (3.8)$$

$$\boldsymbol{\rho}_s = C_{s1}P+C_{s2} \qquad (3.9)$$

$$\alpha_{cs} = \frac{1/\rho f - Vw}{1/\rho s - Vw} \tag{3.10}$$

$$X_w = 50(V_w V_{t\rho} + 60\alpha_{cs} + 0.05W_s + 65.5) \tag{3.11}$$

Where: X_w is the output drum water level. ws, ρ_f, ρs and αcs are the intermediate variables steam flow, density of fluid in system, density of steam and quality of steam respectively. V_t, C_{s1}, C_{s2} and V_w are constant representing total volume of the drum and risers, least squares fitting of steam table and specific volume of water. The boiler turbine unit used to evaluate the models in this report is a 100 Mw oil fired natural circulation drum unit. Full details of the unit are shown in Table 3.1 [19].

Table 3.1: Parameters of boiler turbine 100 Mw in Dr.Shareef

Parameters	Values
Rated power, P_0	100MW
Steam flow at rated load, qs	140kg/sec
Drum steam pressure, P	140kg/cm^2
Superheated steam temperature, Ts	535℃
Volume of drum, Vd	40m^3
Volume of downcomers, Vdc	11m^3
Volume of risers, Vr	34m^3
Mass of water in system at normal operating conditions, Mfw	40,000kg
Mass of steam in system at normal operating conditions, Ms	2,000kg
Feedwater temperature, Tfw	300℃
Specific volume of water at 320 ℃ ,Vw	0.001538m^3
Constant from fitting data to steam tables , Cs	0.8
Constant from fitting data to steam tables, Cs2	-25.6

3.1.2 The linear model

For simplicity the intended stability analysis shall be performed by linearization of the nonlinear model at typical operating points of the drum, a linearized model is obtained from a truncated Taylor series expansion of the non-linear equations. The non-linear dynamics are of the form:

$$\frac{dX}{dt} = f(x, u) \tag{3.12}$$

$$y = g(x, u) \tag{3.13}$$

And linearization of the system about the nominal operating point, (x^0, u^0), requires calculating the liner system matrices as follows [2]:

$$A = [\frac{\partial f}{\partial x}]_{(x0,u0)} \tag{3.14}$$

$$B = [\frac{\partial f}{\partial u}]_{(x^0,u^0)} \tag{3.15}$$

$$C = [\frac{\partial g}{\partial x}]_{(x^0,u^0)} \tag{3.16}$$

$$D = [\frac{\partial g}{\partial u}]_{(x^0,u^0)} \tag{3.17}$$

For $x^0 = [108 \;\; 74.65 \;\; 428]^T$ and $u^0 = [0.34 \;\; 0.69 \;\; 0.436]^T$. The linear approximation to the system is:

$$\frac{d\bar{x}}{dt} = A\bar{x} + B\bar{u} \tag{3.18}$$

$$\bar{y} = C\bar{x} + D\bar{u} \tag{3.19}$$

Where $\bar{x} = x - x^0$, $\bar{y} = y - y^0$, and $\bar{u} = u - u^0$. The linear system matrices are found to be:

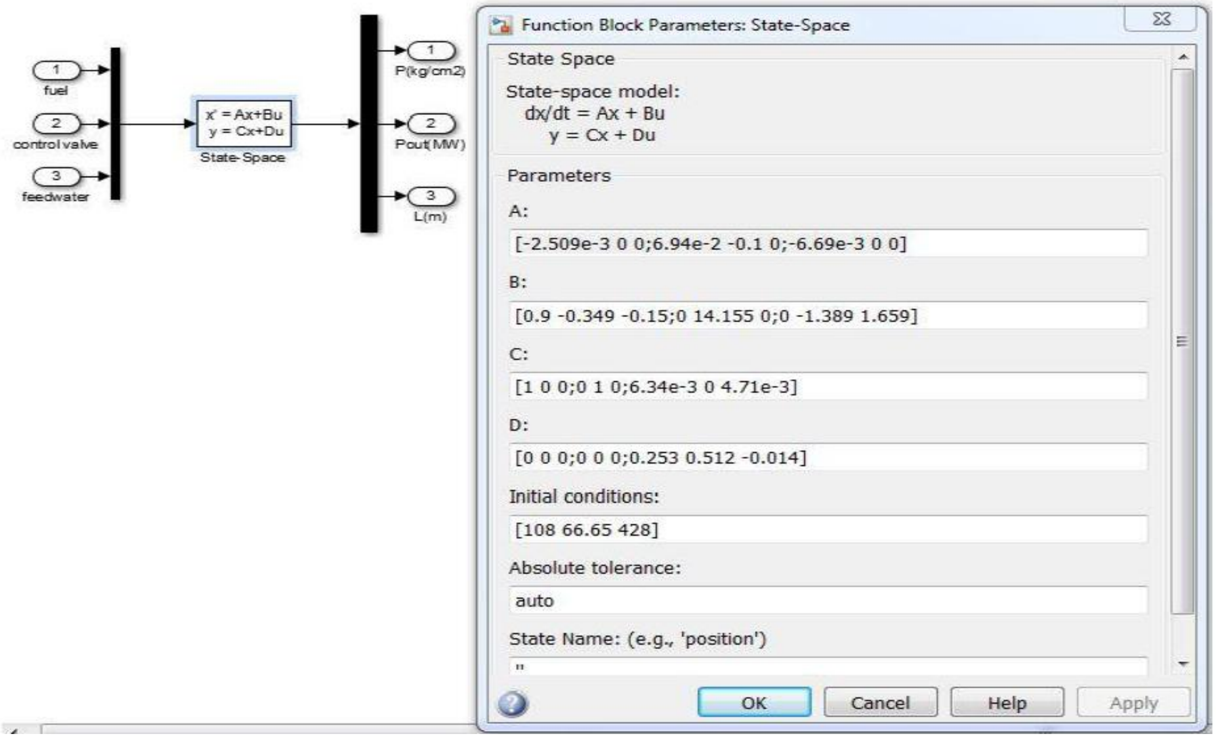
$$A = \begin{bmatrix} -2.509 \times 10-3 & 0 & 0 \\ 694 \times 10-2 & -0.1 & 0 \\ -6.69 \times 10-3 & 0 & 0 \end{bmatrix}$$

$$B=\begin{bmatrix}0.9 & -0.349 & -0.15\\ 0 & 14.155 & 0\\ 0 & -1.389 & 1.659\end{bmatrix}$$

$$C=\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 6.34\times 10-3 & 0 & 4.71\times 10-3.\end{bmatrix}$$

$$D=\begin{bmatrix}0 & 0 & 0\\ 0 & 0 & 0\\ 0.253 & 0.512 & -0.014\end{bmatrix}$$

Figure 3.2 below shown the state space model and how to input it’s parameters in MATLAB/SIMULINK.



Function Block Parameters: State-Space

State Space

State-space model:
dx/dt = Ax + Bu
y = Cx + Du

Parameters

A:
[-2.509e-3 0 0;6.94e-2 -0.1 0;-6.69e-3 0 0]

B:
[0.9 -0.349 -0.15;0 14.155 0;0 -1.389 1.659]

C:
[1 0 0;0 1 0;6.34e-3 0 4.71e-3]

D:
[0 0 0;0 0 0;0.253 0.512 -0.014]

Initial conditions:
[108 66.65 428]

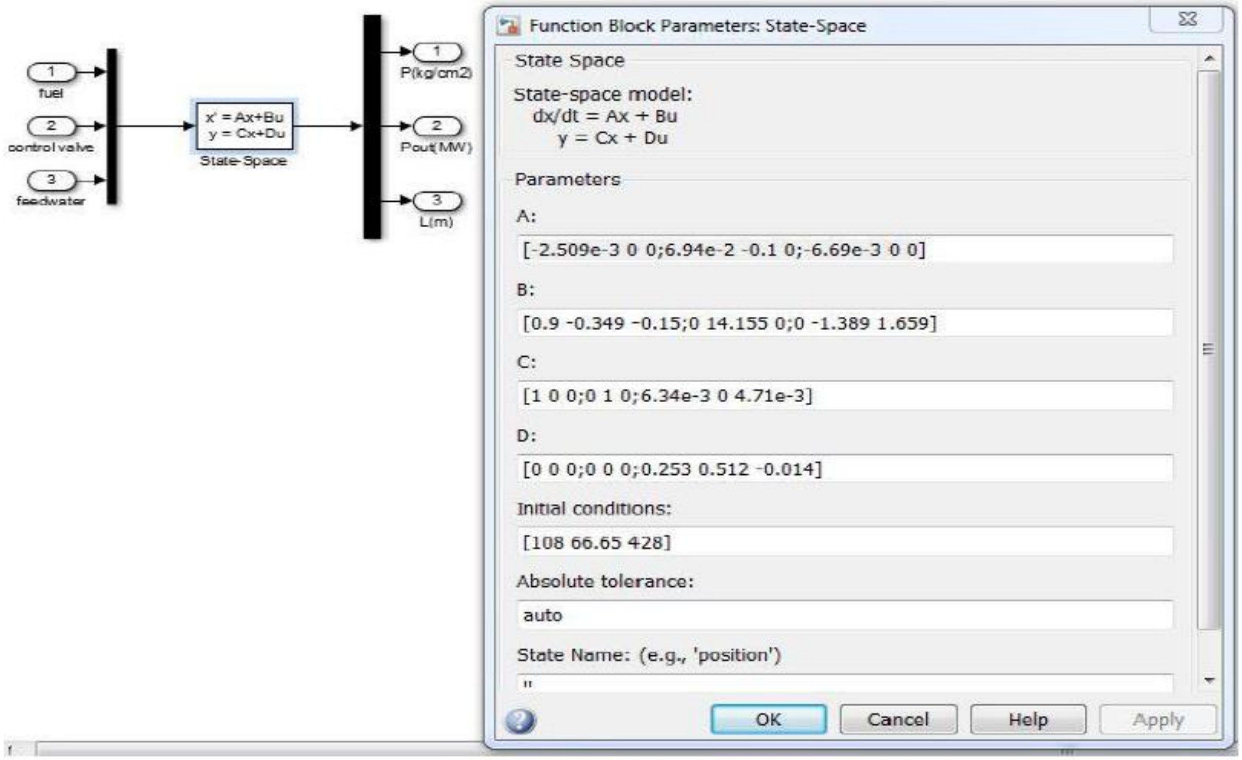
Absolute tolerance:
auto

State Name: (e.g., 'position')
''

Figure 3.2: State space model

3.2 Actuator Dynamics

If control studies are to be under taken with the models presented in this work, then actuator dynamics will be needed. The actuator dealing with the positioning is modeled as a 1st order lag element whose integrator saturation corresponds to the valve position ranging between 0% and 100%. Figure 3.3 gives a block diagram for the realization of such dynamics [17].



Function Block Parameters: State-Space

State Space

State-space model:
dx/dt = Ax + Bu
y = Cx + Du

Parameters

A:
[-2.509e-3 0 0;6.94e-2 -0.1 0;-6.69e-3 0 0]

B:
[0.9 -0.349 -0.15;0 14.155 0;0 -1.389 1.659]

C:
[1 0 0;0 1 0;6.34e-3 0 4.71e-3]

D:
[0 0 0;0 0 0;0.253 0.512 -0.014]

Initial conditions:
[108 66.65 428]

Absolute tolerance:
auto

State Name: (e.g., 'position')
''

Figure 3.2: State space model

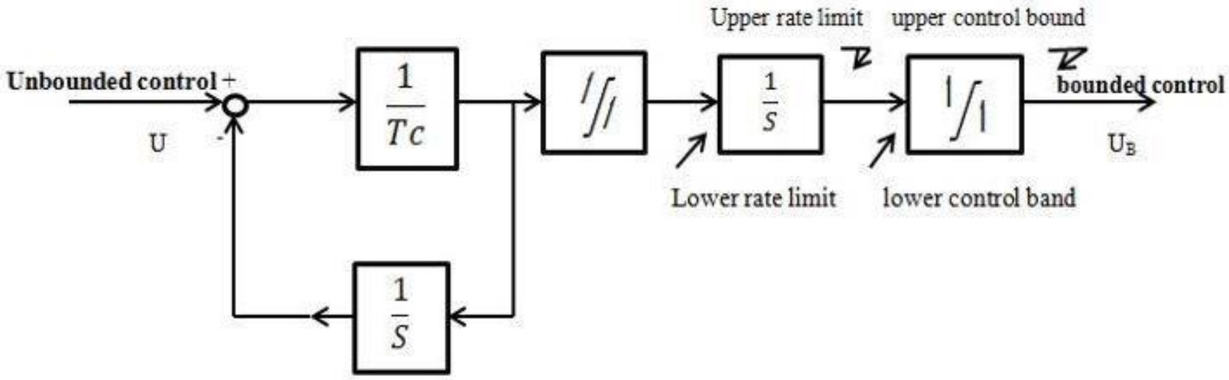


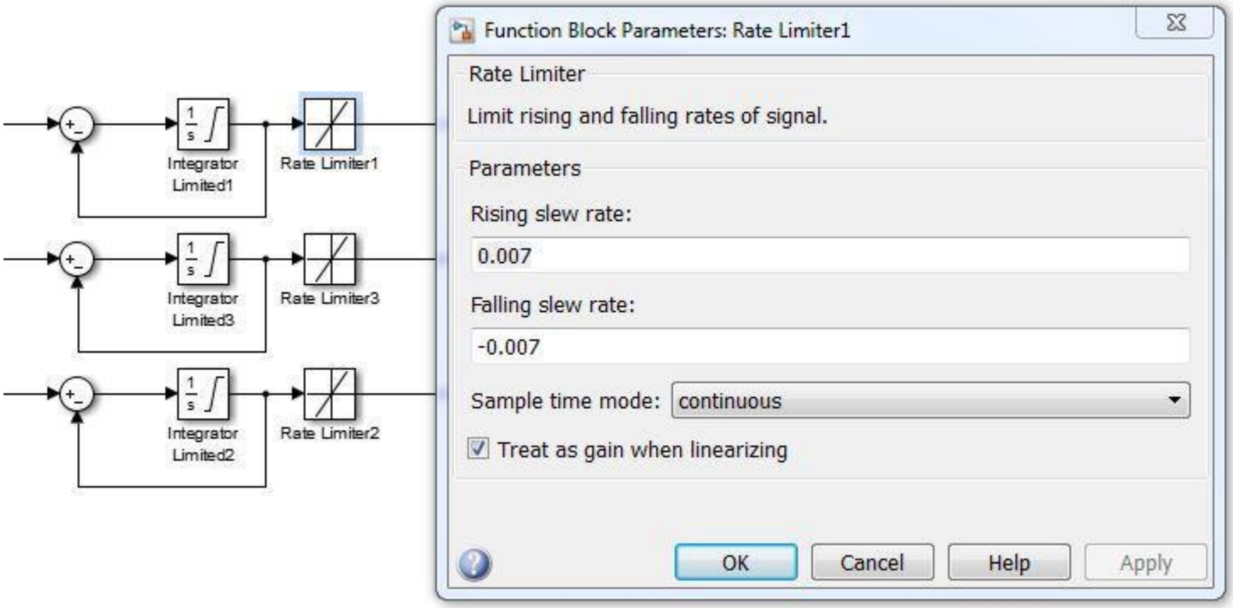
Figure 3.3: Representation of actuator dynamics

3.2.1 Fuel flow

The rate limiting for the actuator used to operate the fuel flow valve is by the equation:

$$\left|\frac{du_1}{dt}\right| \leq \frac{0.007}{second} \qquad 0 < u1 < 1 \qquad (3.20)$$

Figure 3.4 shows the simulation of fuel flow actuator and setting limit rate in MATLAB.



Function Block Parameters: Rate Limiter1

Rate Limiter

Limit rising and falling rates of signal.

Parameters

Rising slew rate: 0.007

Falling slew rate: -0.007

Sample time mode: continuous

☑ Treat as gain when linearizing

Figure 3.4: Fuel actuator

3.2.2 Feedwater flow

The rate limiting for the actuator used to operate the feedwater flow valve is by the equation:

$$\left|\frac{du_3}{dt}\right| \leq \frac{0.05}{second} \qquad 0 < u3 < 1 \qquad (3.21)$$

Figure 3.5 shows the simulation of feedwater flow actuator and setting limit rate in MATLAB.

3.2.3 Control valve

The rate limiting of opening and closing for the actuator used to the power output valve is by the equation:

i. Opening or upper rate

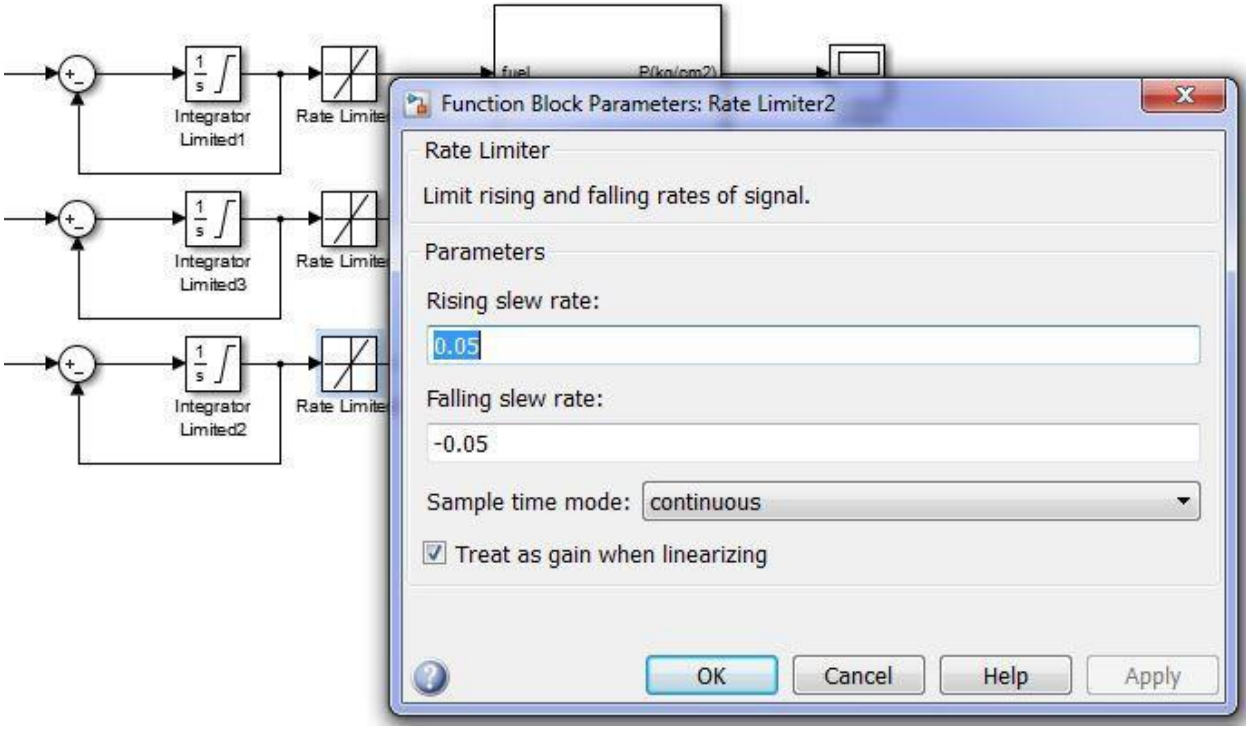
$$\left|\frac{du_2}{dt}\right| \leq \frac{0.2}{second} \tag{3.22}$$

i. Closing or lower rate limit

$$\left|\frac{du_2}{dt}\right| \leq \frac{2}{second} \tag{3.23}$$

$$0 < u_1 < 1$$

Figure 3.6 shows the simulation of control valve actuator and setting for upper rate and lower rate limit in MATLAB.



Function Block Parameters: Rate Limiter2

Rate Limiter

Limit rising and falling rates of signal.

Parameters

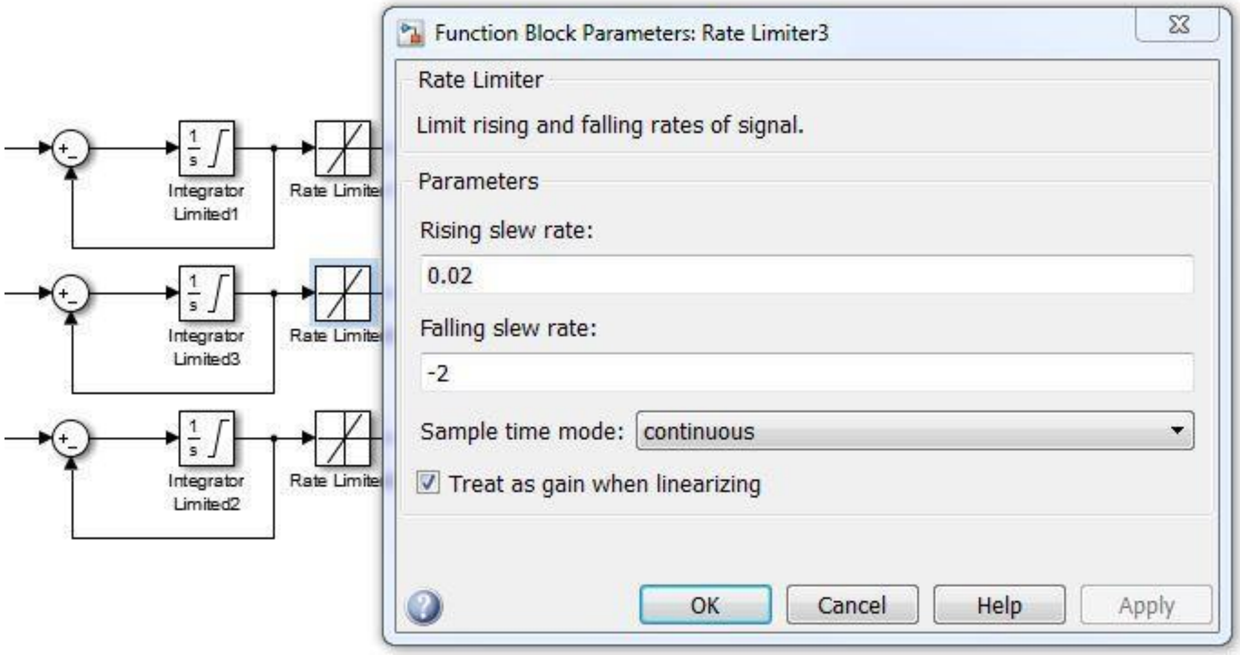
Rising slew rate: 0.05

Falling slew rate: -0.05

Sample time mode: continuous

☑ Treat as gain when linearizing

Figure 3.5: Feedwater actuator



Function Block Parameters: Rate Limiter3

Rate Limiter

Limit rising and falling rates of signal.

Parameters

Rising slew rate: 0.02

Falling slew rate: -2

Sample time mode: continuous

☑ Treat as gain when linearizing

Figure 3.6: Control valve

3.3 System Control Design

In this section, typical methods used to develop a conventional PI controller and Fuzzy Logic Controller (FLC) by using MATLAB/SIMULINK. The target of the thesis is control the boiler for the pressure, power output and water level. The results for both controller simulations are compared and discuss in chapter four.

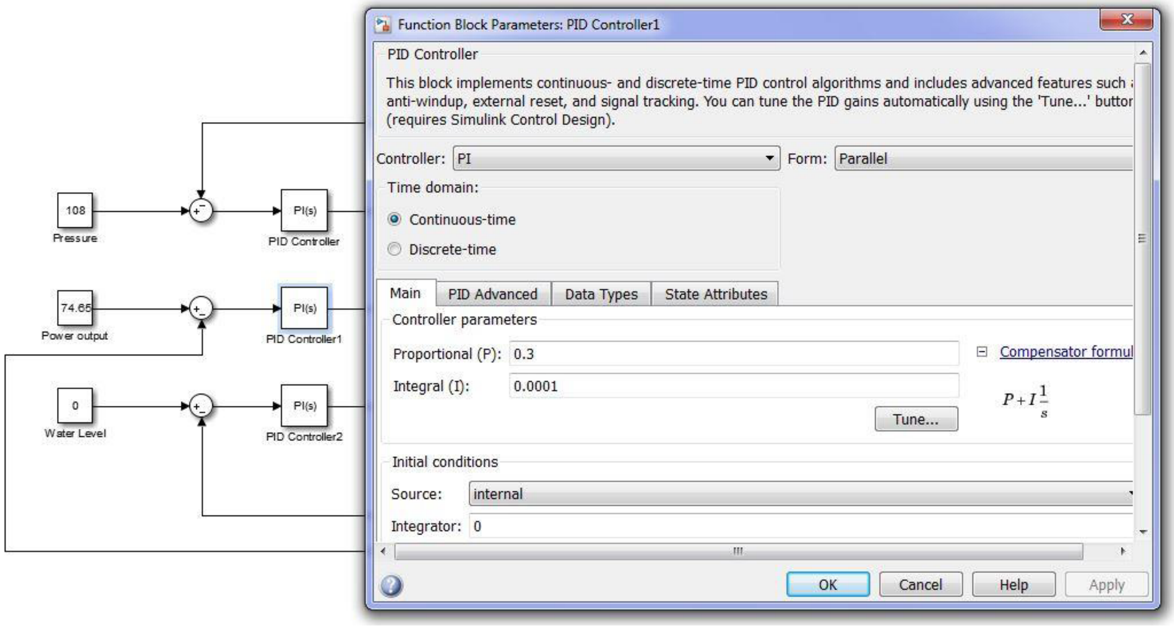
3.3.1 PI controller design

Some applications may require using only one or two modes to provide the appropriate system control. This is achieved by setting the gain of undesired control output to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control action. PI controllers are particularly common, since derivative action is very sensitive to measurement noise, and the absence of an integral value may prevent the system from reaching its target value due to the control action. Now investigate the design of PI controller to control the boiler. To controls the pressure and water level of the drum to coincide with desired pressure and water level by changing fuel flow valve ratio and feedwater flow valve ratio respectively. And control power output from turbine by changing control valve ratio.

Figure 3.7 shows the Simulink block diagram of PI controller. Simulink continuous PID block offers functionalities which meets exactly our needs, it can easy configuration by set controller parameter as shown in Figure 3.7. A separate PI controller has been designed for any variable (pressure, water level and power output) without considering any sort of coupling or interaction between both outputs. In the coupled PI controller design the gains are tuned in two stages. The first stage consists of tuning the proportional gains in the PI controller only and leaving the others fixed at zero. The initial gains are selected at random between some coarse upper and lower bounds and tuned through iteration. Once some pre-specified convergence criterion has been achieved, the best fit triplet of proportional gains is designated as the result for the stage. The second stage is to tuning the integral gain of the three control units. In the same way, the selection of gain begins randomly and through repetition until the required response is met. The results of tuning PI controller explained in Table 3.2.

Table 3.2: PI controller parameters

PI-controller parameter		
Controller	k_p	k_I
Pressure	3	0.001
Power output	0.3	0.0001
Water level	40	0.001



PID Controller

This block implements continuous- and discrete-time PID control algorithms and includes advanced features such
anti-windup, external reset, and signal tracking. You can tune the PID gains automatically using the 'Tune...' butto
(requires Simulink Control Design).

Controller: PI
Form: Parallel
Time domain:
● Continuous-time
○ Discrete-time

Controller parameters
Proportional (P): 0.3
Integral (I): 0.0001
Compensator formul

$P+I\frac{1}{s}$

Initial conditions
Source: internal
Integrator: 0

Figure 3.7: The SIMULINK block diagram of PI controller PI Controller

3.3.2 Fuzzy controller design

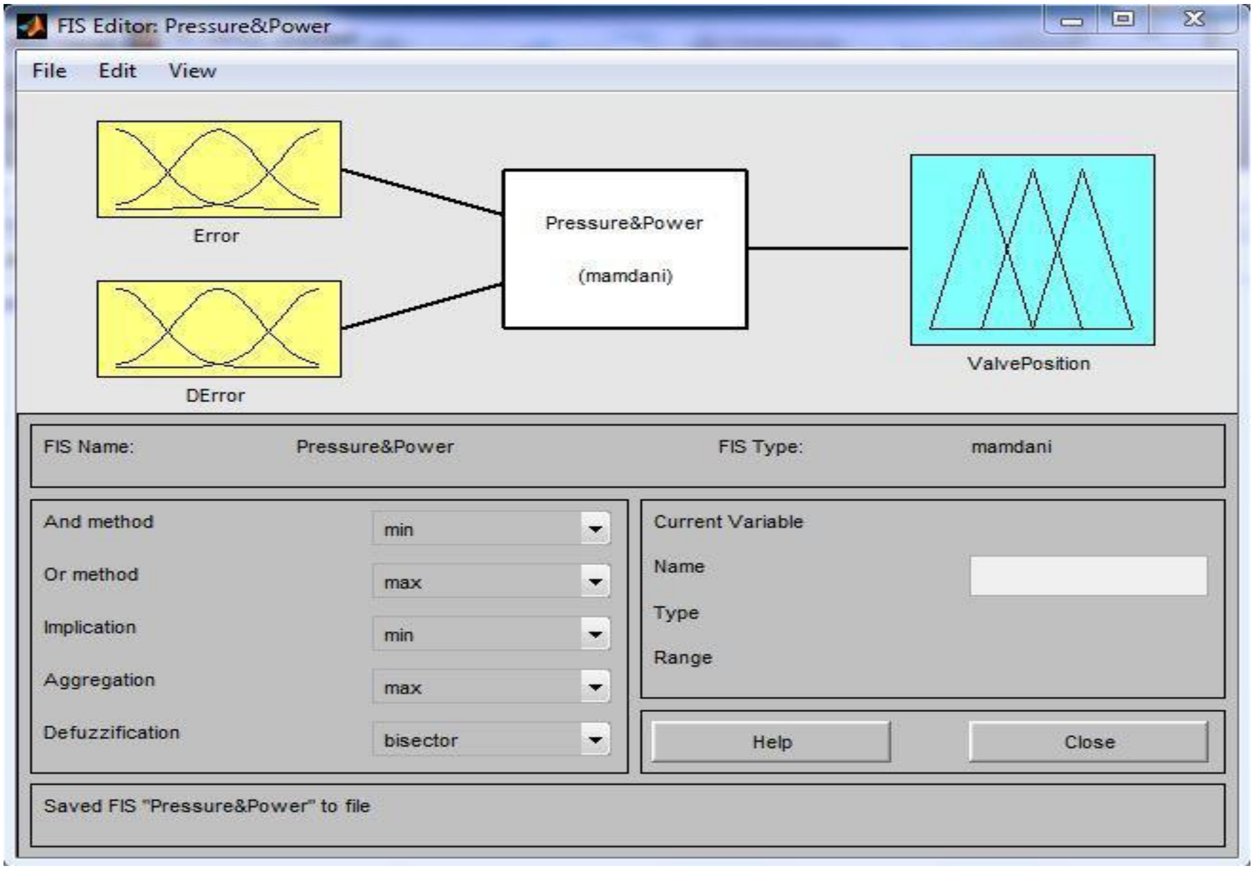
The most important aspect in fuzzy logic control system designs start with a process of converting the measured inputs called crisp values, into the fuzzy linguistic values used by the fuzzy reasoning mechanism. The process of reasoning mechanism will perform fuzzy logic operations and result the action according to the fuzzy inputs. A collection of the expert control rules known as knowledge needed to achieve the control goal. In this fuzzy model there are three controller (pressure, power output and water level), for the two input variable of fuzzy system the Error (E) and Change in Error (CE). And the fuel flow valve position, steam control valve position and feedwater flow valve position are outputs corresponding to the pressure, power output and water level respectively.

3.3.3 Fuzzy logic toolbox

There are five primary Graphical User Interface (GUI) tools for building, editing and observing fuzzy inference systems in the toolbox. These GUI are dynamically linked and if the changes make to the FIS to one of the toolbox, the effect can be seen in other GUIs:

A. Fuzzy inference system editor

The FIS editor displays information about a fuzzy inference system. To open the fuzzy logic designer, type Fuzzy command at the MATLAB on command window appears as shown in Figure 3.8. The FIS editor opens and displays a diagram of the fuzzy inference system with the names of each input variable on the left, and those of each output variable on the right, as shown in the Figure 3.8. The sample membership functions shown in the boxes are just icons and do not depict the actual shapes of the membership functions. Note: in work, two FIS files are designed; one for pressure and power output other one for drum water level.



FIS Name: Pressure&Power

FIS Type: mamdani

And method: min

Or method: max

Implication: min

Aggregation: max

Defuzzification: bisector

Saved FIS "Pressure&Power" to file

Figure 3.8: Pressure and power output FISB.

B. Membership function editor

The membership function editor tool is used to display and edit all of the membership functions associated with all of the input and output variables for the entire fuzzy inference system. The membership function editor shares some features with the FIS editor. A triangular membership functions are used for the fuzzy set of input and output vectors. Different linguistic variables are considered and details of these variables are shown in Table 3.3.

Table 3.3: Linguistic variables of fuzzy set

Error(E)		Change in Error(CE)		Controller Output(U)	
NL	Negative Large	NL	Negative Large	FC	Fully Close
NM	Negative Medium	NM	Negative Medium	C	Close
Z	Zero	Z	Zero	M	Medium
PM	Positive Medium	PM	Positive Medium	O	Open
PL	Positive Large	PL	Positive Large	FO	Fully Open

Triangular membership functions for pressure and power output, Figure 3.9 shows the membership function of the input error (E), Figure 3.10 shows the membership function of the input change in error (CE) and Figure 3.11 shows the membership function of the output valve position. The second fuzzy set designed for water level, Figure 3.12 shows the membership function of the input error (E), Figure 3.13 shows the membership function of the input change in error (CE) and Figure 3.14 shows the membership function of the output valve position.

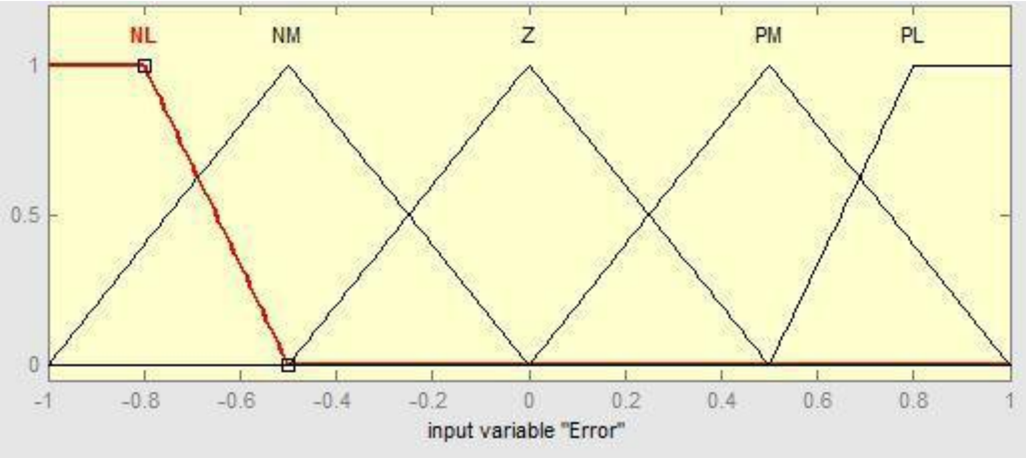


Figure 3.9: Input 1 (Error) in FIS editor for pressure and power

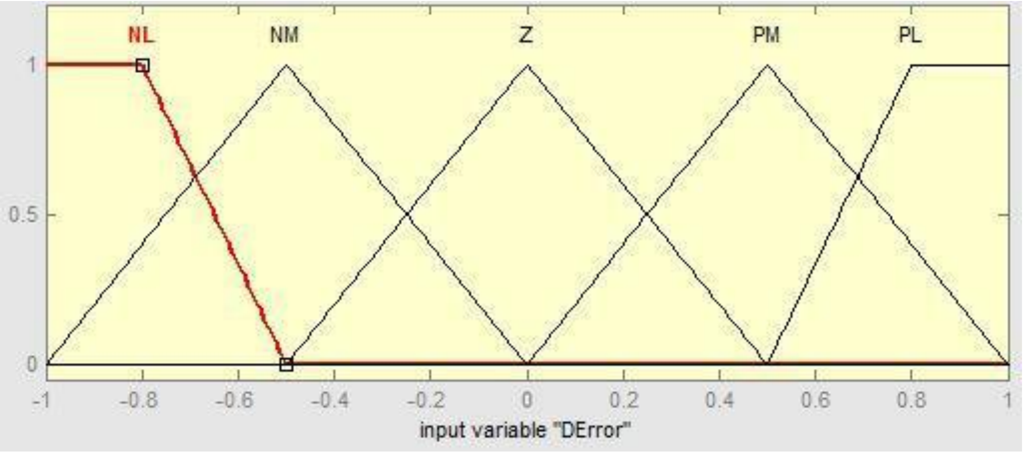


Figure 3.10: Input 2 (DError) in FIS editor for pressure and power

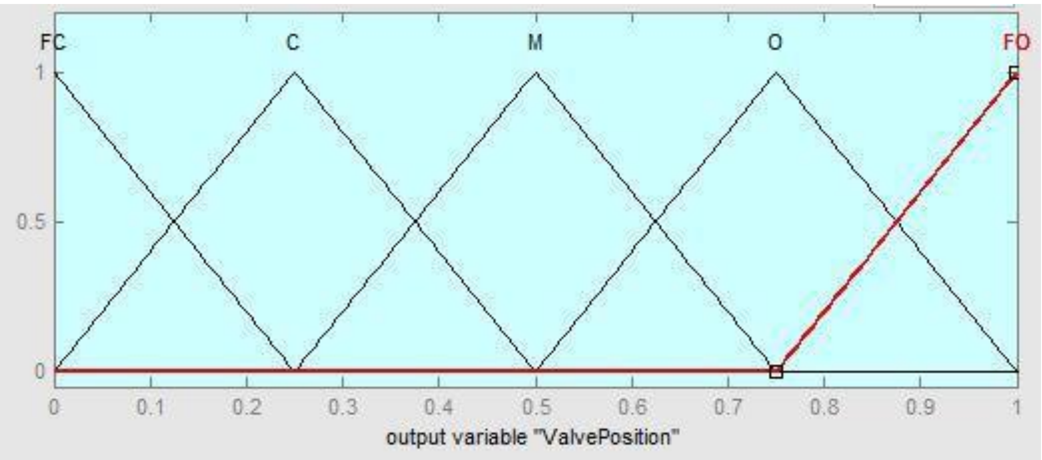


Figure 3.11: Output (Valve position) in FIS editor for pressure and power

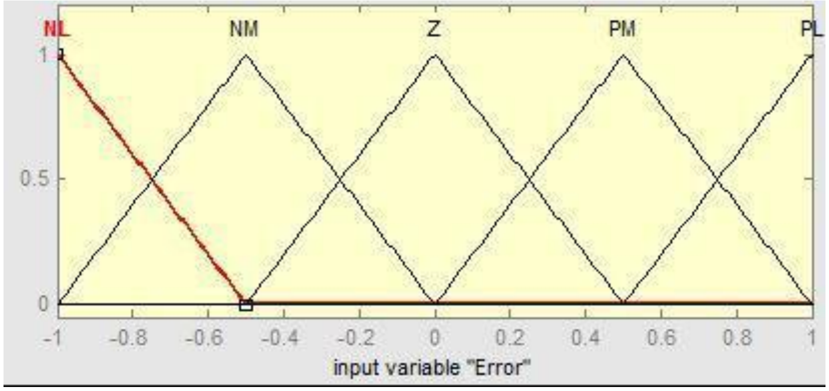


Figure 3.12: Input 1 (Error) in FIS editor for level

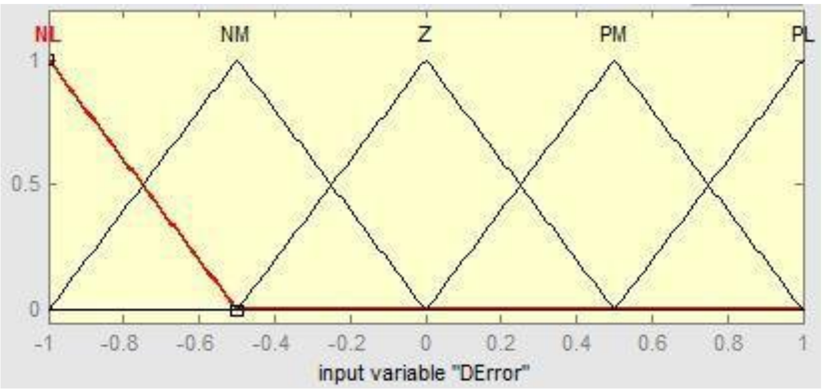


Figure 3.13: Input 1 (DError) in FIS editor for level

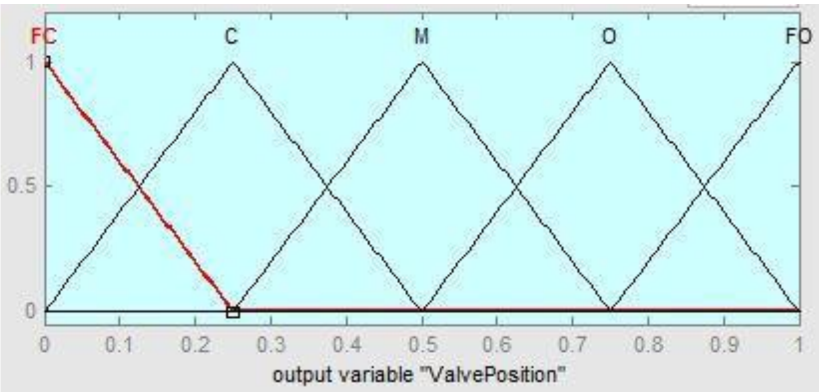
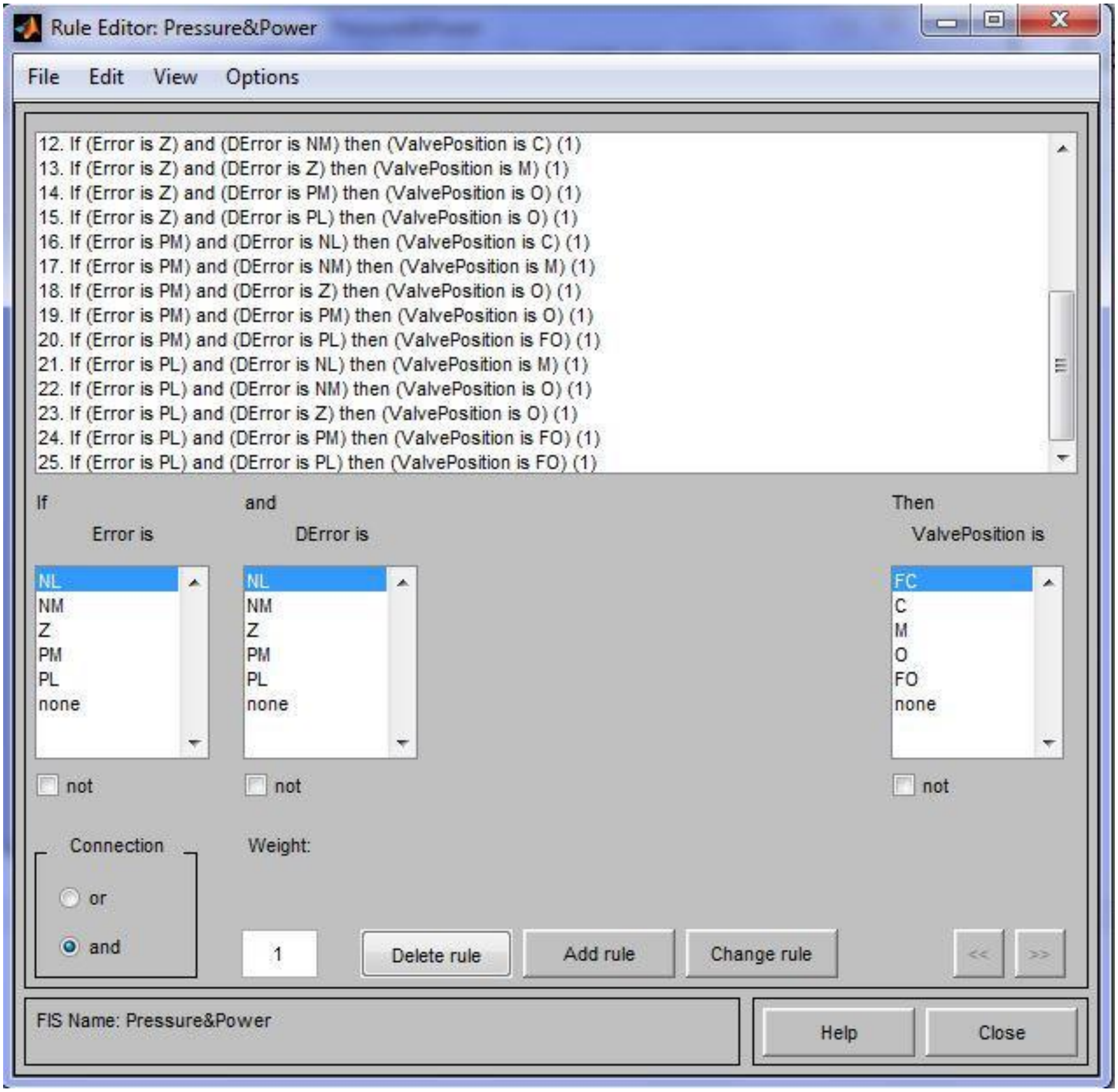


Figure 3.14: Output (Valve position) in FIS editor for level

C. Rule editor

Constructing rules using the graphical rule editor interface is fairly self-evident. Based on the descriptions of the input and output variables defined with the FIS editor, the rule editor allows to construct the rule statements automatically. As shown in Figure 3.15 with rule editor it can:

- Create rules by selecting an item in each input and output variable box, selecting one connection item, and clicking add rule. It can choose none as one of the variable qualities to exclude that variable from a given rule and choose not under any variable name to negate the associated quality.
- Delete a rule by selecting the rule and clicking delete rule.
- Edit a rule by changing the selection in the variable box and clicking change rule.
- Specify weight to a rule by typing in a desired number between 0 and 1 in weight. If you do not specify the weight, it is assumed to be unity (1).



12. If (Error is Z) and (DError is NM) then (ValvePosition is C) (1)
13. If (Error is Z) and (DError is Z) then (ValvePosition is M) (1)
14. If (Error is Z) and (DError is PM) then (ValvePosition is O) (1)
15. If (Error is Z) and (DError is PL) then (ValvePosition is O) (1)
16. If (Error is PM) and (DError is NL) then (ValvePosition is C) (1)
17. If (Error is PM) and (DError is NM) then (ValvePosition is M) (1)
18. If (Error is PM) and (DError is Z) then (ValvePosition is O) (1)
19. If (Error is PM) and (DError is PM) then (ValvePosition is O) (1)
20. If (Error is PM) and (DError is PL) then (ValvePosition is FO) (1)
21. If (Error is PL) and (DError is NL) then (ValvePosition is M) (1)
22. If (Error is PL) and (DError is NM) then (ValvePosition is O) (1)
23. If (Error is PL) and (DError is Z) then (ValvePosition is O) (1)
24. If (Error is PL) and (DError is PM) then (ValvePosition is FO) (1)
25. If (Error is PL) and (DError is PL) then (ValvePosition is FO) (1)

Connection: ● and

Weight: 1

FIS Name: Pressure&Power

Figure 3.15: Rule editor

Table 3.4 shows the corresponding rule table for the proposed fuzzy control system. The top row of the matrix indicates the fuzzy sets of the error variable E and the left column indicates the change in error variable CE and the output variable U is shown in the body of the matrix.

Table 3.4: Rule base for fuzzy logic controller

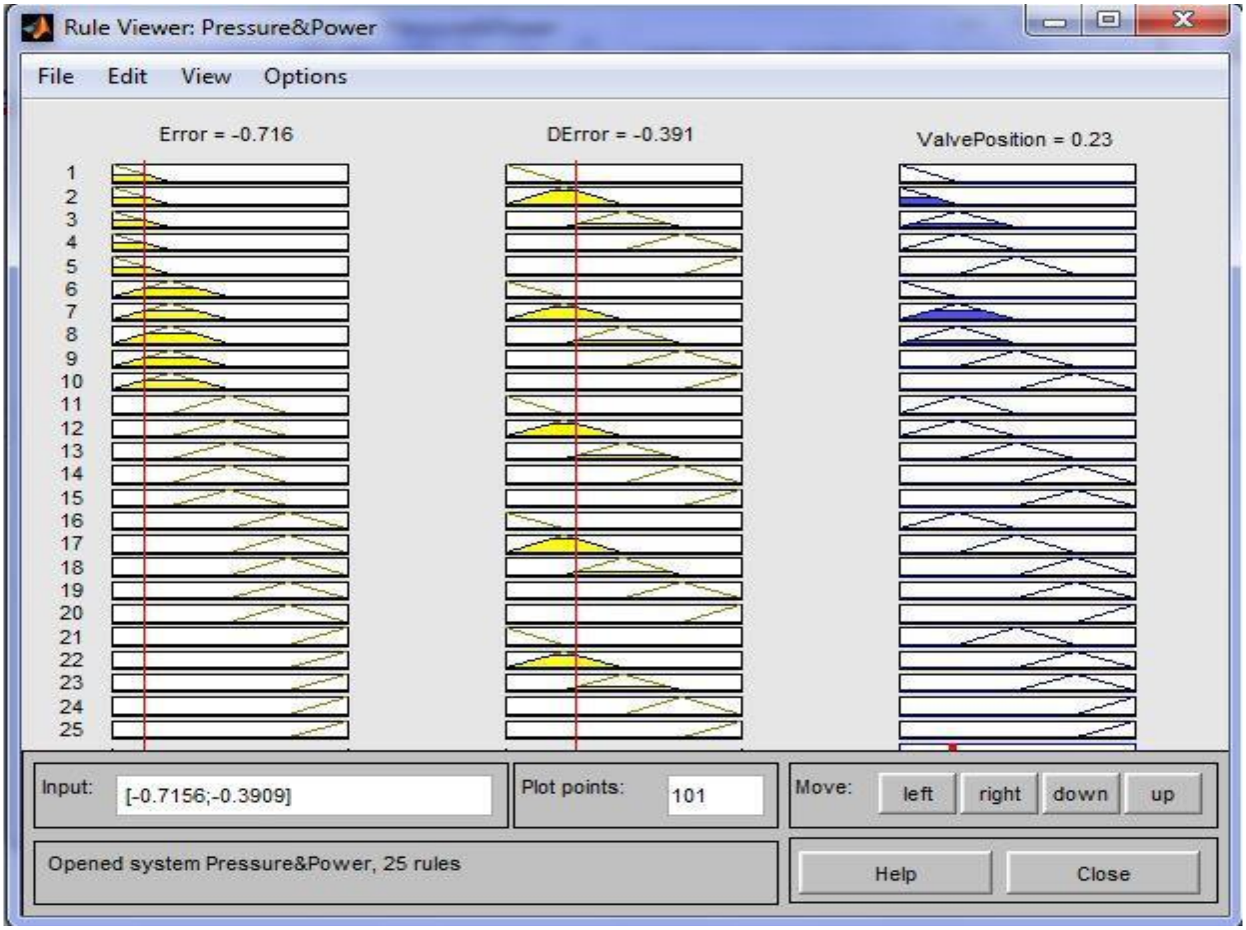
E CE	NL	NM	Z	PM	PL
NL	FC	FC	C	C	M
NM	FC	C	C	M	O
Z	C	C	M	O	O
PM	C	M	O	O	FO
PL	M	O	O	FO	FO

D. The rule viewer

Figure 3.16 shows the rule viewer, it is allows interpreting the entire fuzzy inference process at once. The rule viewer also shows how the shape of certain membership functions influences the overall result. Because it plots every part of every rule, it can become unwieldy for particularly large systems, but, for a relatively small number of inputs and outputs, it performs well (depending on how much screen space you devote to it) with up to 30 rules and as many as 6 or 7 variables.

E. The surface viewer

Upon opening the surface viewer, a three-dimensional curve is seen that represents the mapping from food and service quality to tip amount. Because this curve represents a two-input one-output case, it can see the entire mapping in one plot. When moves beyond three dimensions overall, to encounter trouble displaying the results are started. The surface viewer has a special capability that is very helpful in cases with two (or more) inputs and one output: the axes can be grabbed, using the mouse and reposition them to get a different three-dimensional view on the data as shown in Figure 3.17.



Error = -0.716

DError = -0.391

ValvePosition = 0.23

Input: [-0.7156;-0.3909]

Plot points: 101

Opened system Pressure&Power, 25 rules

Figure 3.16: The rule viewer

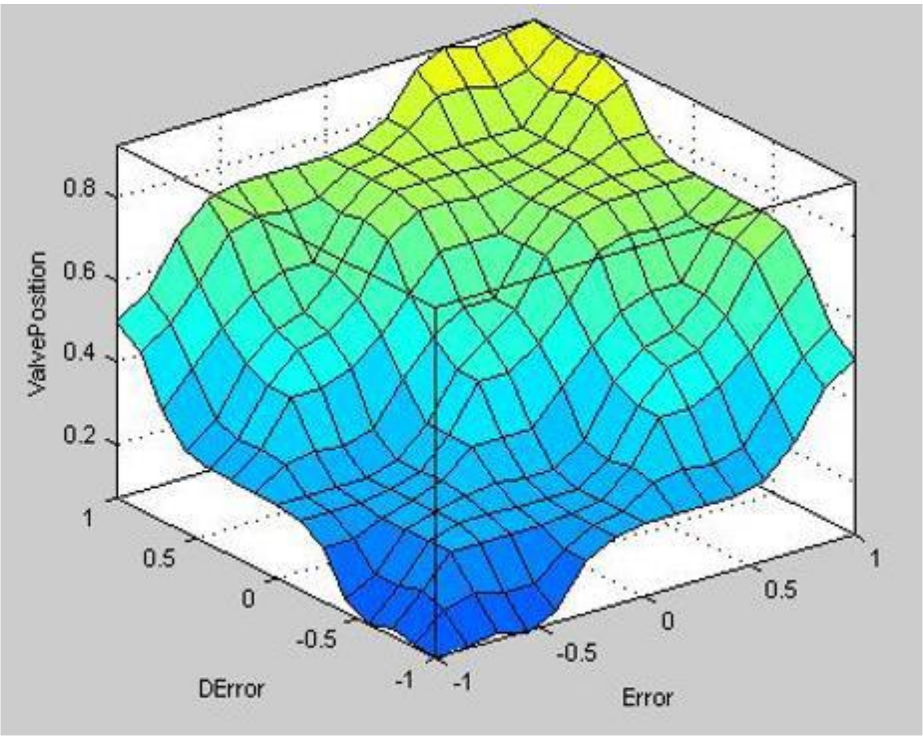


Figure 3.17: The surface viewer

CHAPTER FOUR
SYSTEM SIMULATION RESULTS AND DISCUSSIONS

CHAPTER FOUR
SYSTEM SIMULATION RESULTS AND DISCUSSIONS

4.1 Introduction

Computer modeling and simulation is widely used to study the behavior of proposed system and to decide whether the new control design processes are valid in order to avoid the mistakes early in simulations before actual real implementation. As has been stated before, the controller cannot be tested on a real boiler system. To simulate the system, a MATLAB/SIMULINK is used. This chapter show the simulation results of the uncontrolled boiler turbine, also shows the simulation results of the PI controller and the fuzzy logic controller. The duration of the simulation is 1000 seconds, which is enough to view the response of the component and overall system. And set point values are choice as below:

Pressure = 108kg/cm^2
Power output = 74.65MW.
Water level = 0m.

4.2 Uncontrolled System

The close loop response was studied by simulating the model consisting of the boiler turbine unit and actuator valves with feedback control system. This response gives a good initial indication of a model potential.

Figure 4.1 is the Simulink model for the boiler without any controller. It also shows the pressure output used as feedback for fuel flow rate, power output used as feedback for steam control and the water level used as feedback for feedwater flow rate. The feedback system compares the set point with actual output then produces the error signal. The actuator receives error signal and work to limit it between 0 and 1, the valve open or close according to this value. This process continues to seek access to the reference value.

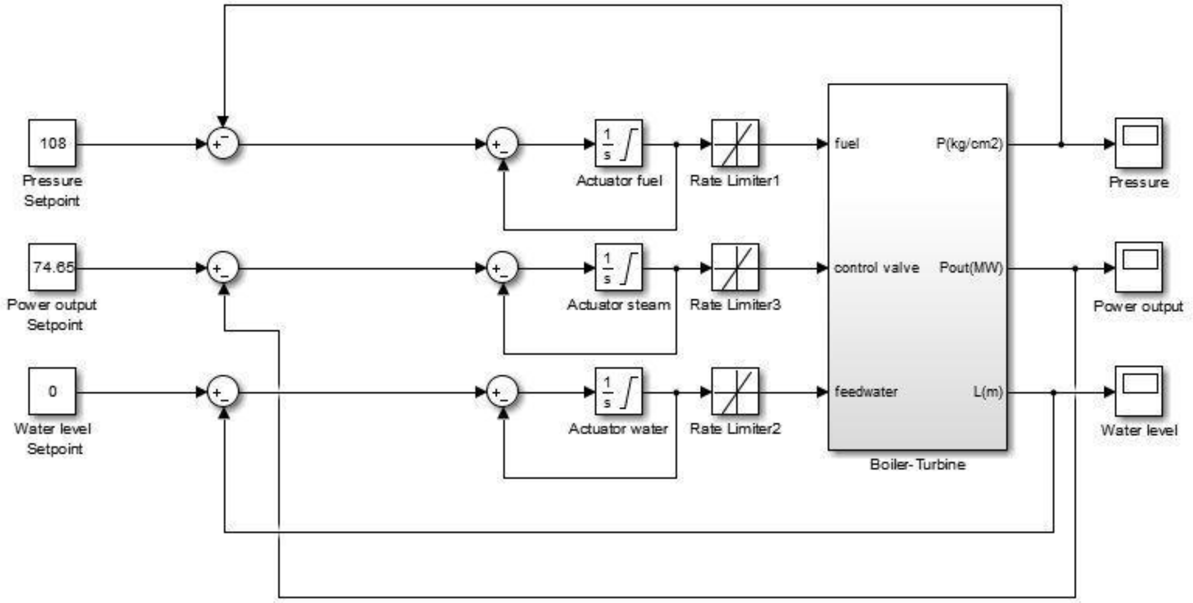


Figure 4.1: Simulink model of uncontrolled boiler turbine

Figure 4.2 shows the response of the pressure. Figure 4.3 shows the response of the power output also oscillating. Figure 4.4 shows the response of the water level.

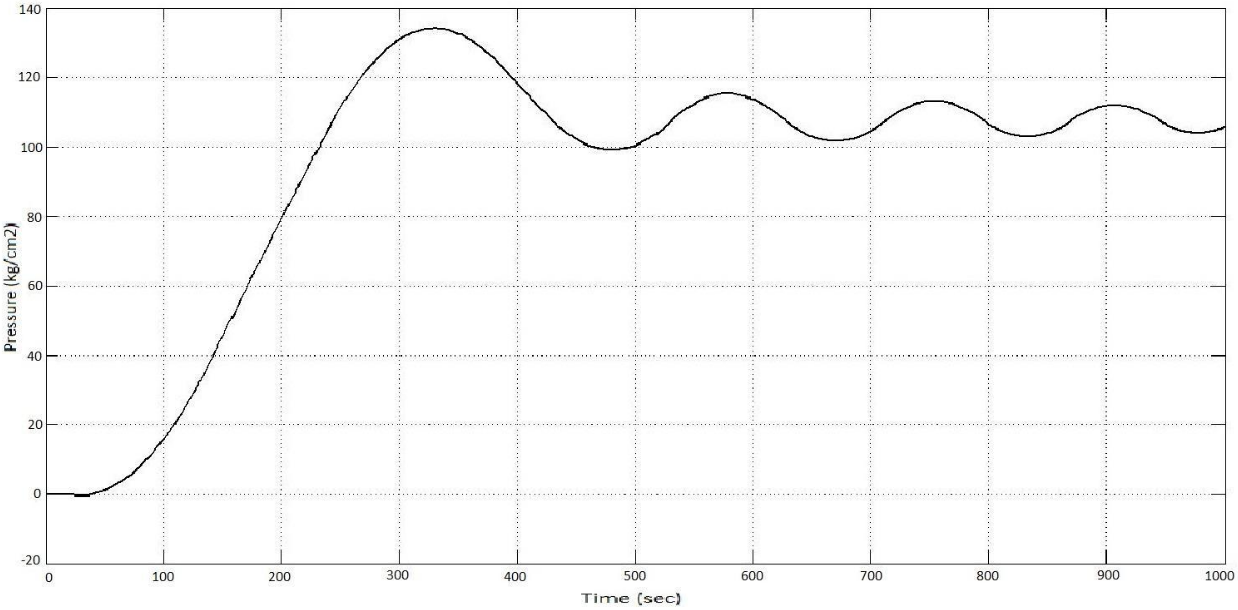


Figure 4.2: Pressure response for uncontrolled system

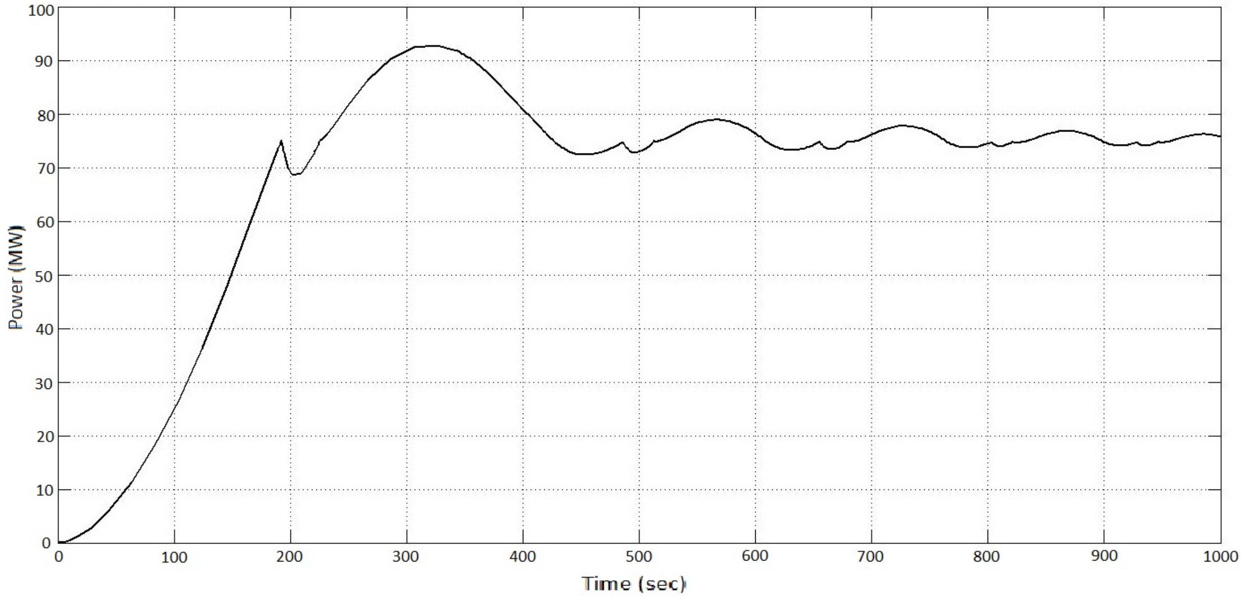


Figure 4.3: Power output response for uncontrolled system

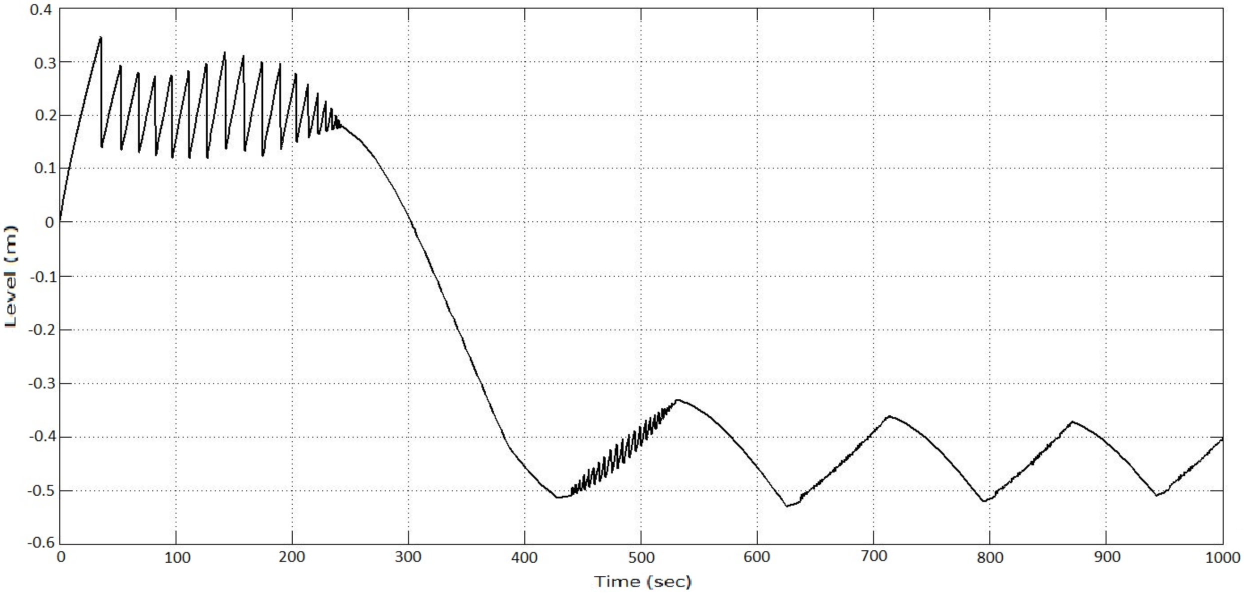


Figure 4.4: Water level response for uncontrolled system

4.3 System with PI Controller

In this section the controls boiler turbine using conventional PI controller. As mentioned earlier in chapter two, PI control is a popular conventional approach. The parameter calculated in previous chapter (Table 3.3). The simulation and results of PI controller as bellowed. This scheme in conventional method to control boiler turbine a separate PI controller are used for any output variables with feedback system as shown in Figure 4.5. A PI controller attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting corrective action that can adjust the process accordingly and rapidly, to keep the error minimal.

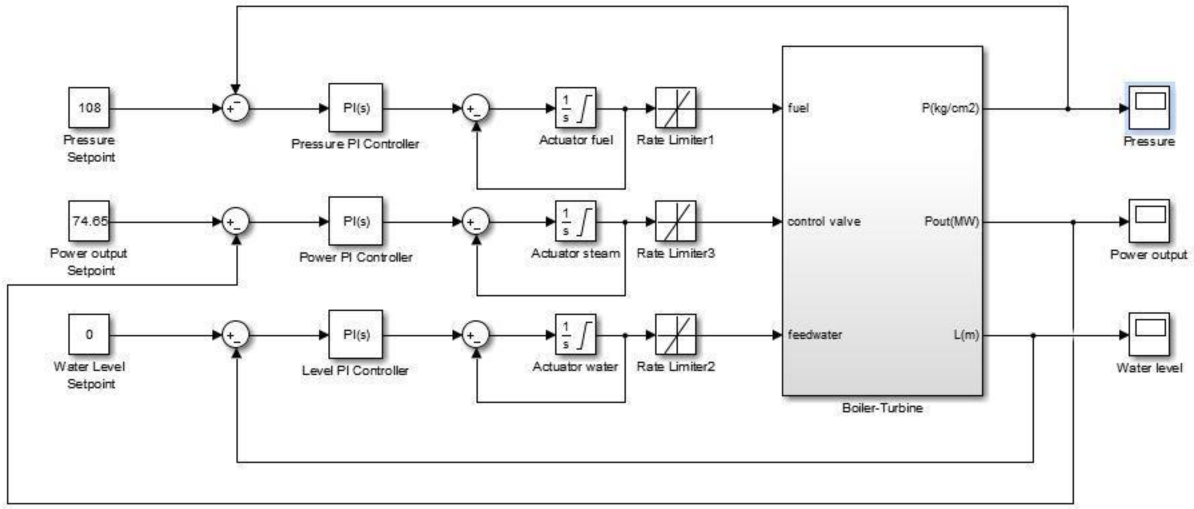


Figure 4.5: Simulink model of boiler turbine using PI controller.

Figure 4.6 shows the pressure response with PI controller it can observe that the response of the pressure still oscillating with little steady state error but there is big overshoot. Figure 4.7 shows the power output response with PI controller, overshoot is illustrated. Figure 4.8 shows water level response with PI controller initially increases due to feedwater. After that decrease unit pressure stabilizes then oscillating.

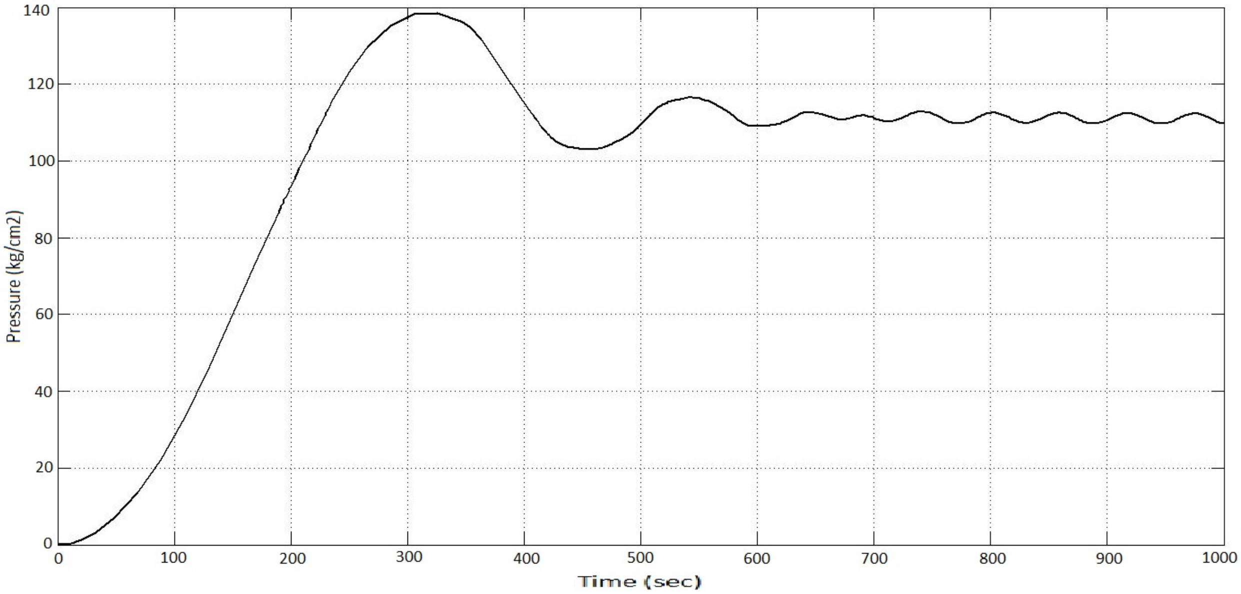


Figure 4.6: Pressure response with PI controller

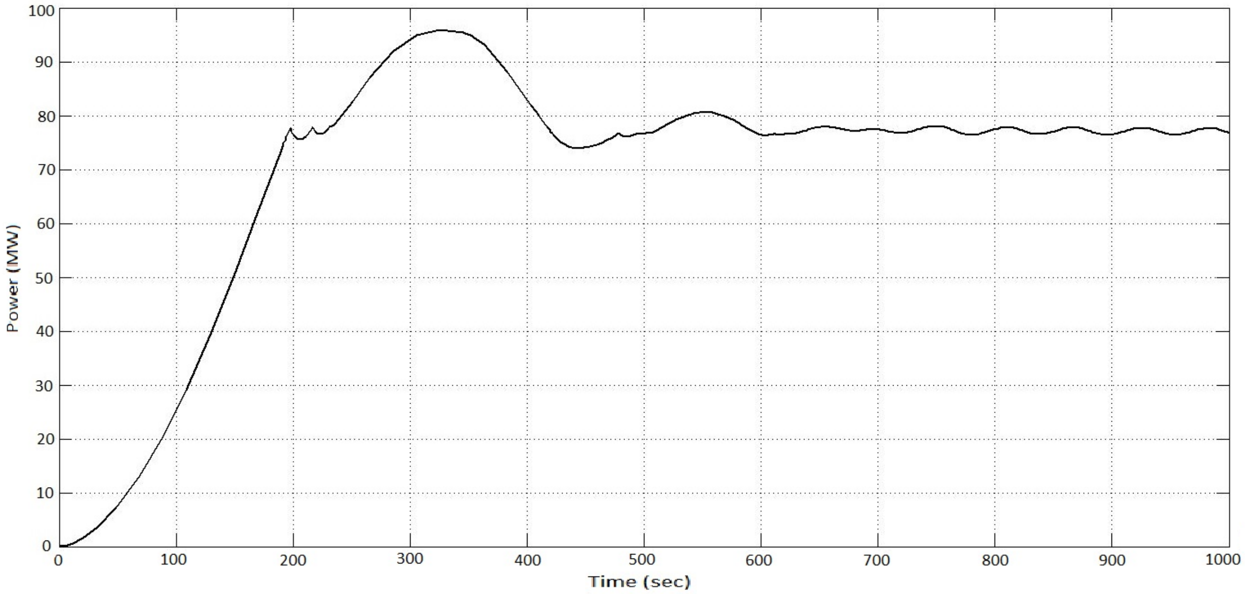


Figure 4.7: Power output response with PI controller

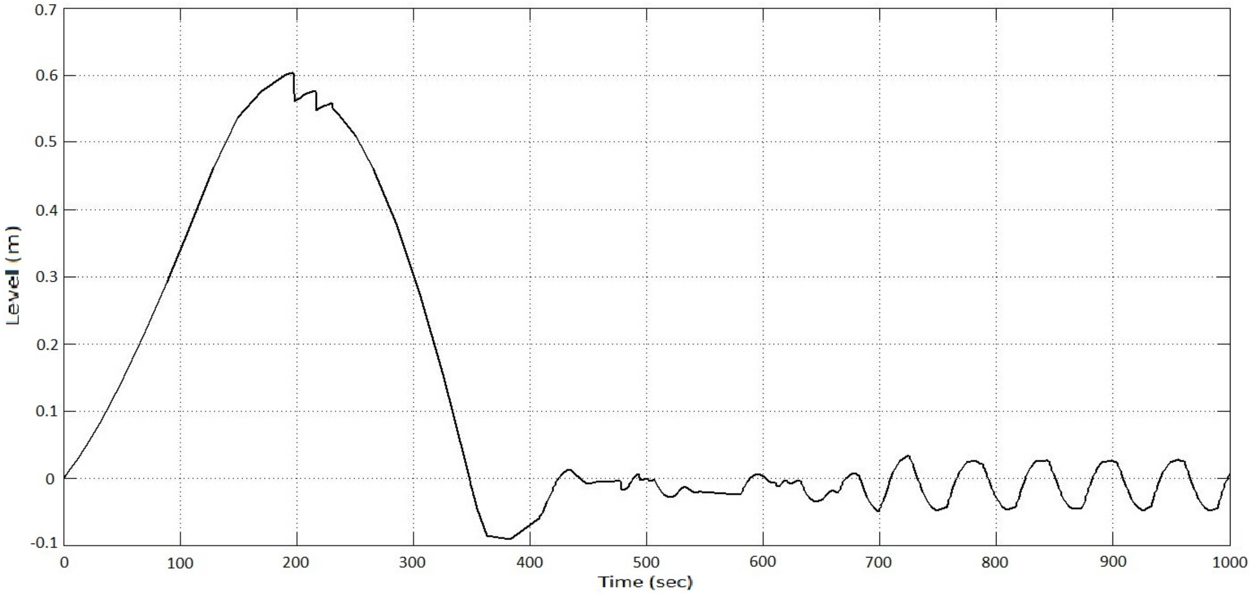
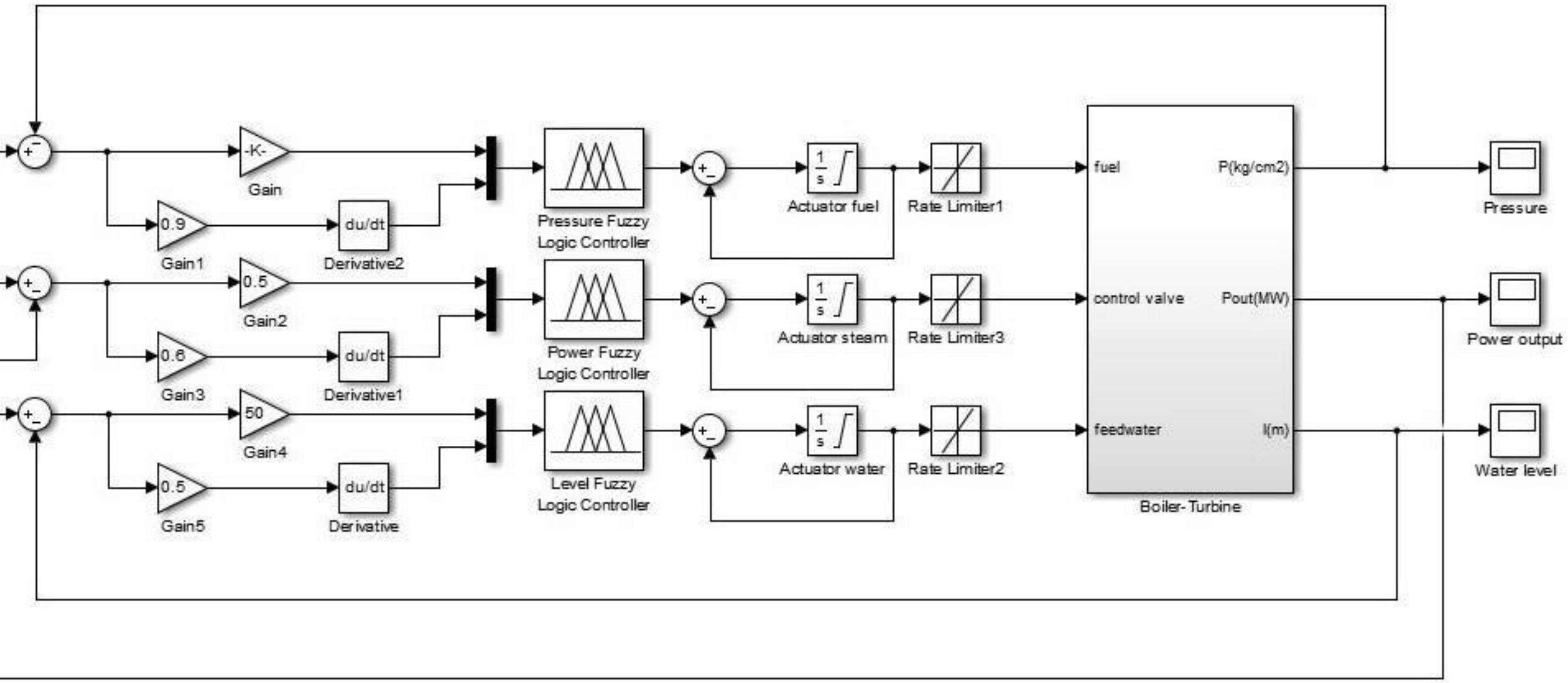


Figure 4.8: Water level response with PI controller

4.4 System with Fuzzy Logic Controller

The objective of this study is to develop a control system for the boiler using a fuzzy logic controller. The Simulink block diagram and results are shown below In Figure 4.9 shows the Simulink model of boiler turbine using fuzzy controller it’s seen that there is individual fuzzy controller for each variable with feedback from output to compare with the set point and then produce the error. Fuzzy controller has two input error and change in error. First input the error is taken directly from the comparison and change in error through derivative function. A gain for inputs error and change in error are used to scale the signal to be suitable with membership function.



Gain
Gain1
Gain2
Gain3
Gain4
Gain5
-K-
0.9
0.5
0.6
50
0.5
du/dt
Derivative2
Derivative1
Derivative
Pressure Fuzzy Logic Controller
Power Fuzzy Logic Controller
Level Fuzzy Logic Controller
Actuator fuel
Actuator steam
Actuator water
Rate Limiter1
Rate Limiter3
Rate Limiter2
fuel
control valve
feedwater
P(kg/cm2)
Pout(MW)
l(m)
Boiler- Turbine
Pressure
Power output
Water level

Figure 4.9: Simulink model of boiler turbine using fuzzy logic controller

In this study the performance of the drum pressure, power output and level for fuzzy logic controller instead conventional controller is illustrated. Figure 4.10 shows the pressure response with fuzzy controller. It started increasing slowly until it reaches the set point. Also we observed there is no overshoot. In Figure 4.11 shows the power output response with fuzzy controller, it increasing depend on the pressure. After the pressure reaches enough value it will settle down. Figure 4.12 shows the water level response. The drop pressure in the start across the feedwater causing increasing in water level. Oscillation in the water level is a result of the steam mass fraction and steam bubbles under the water.

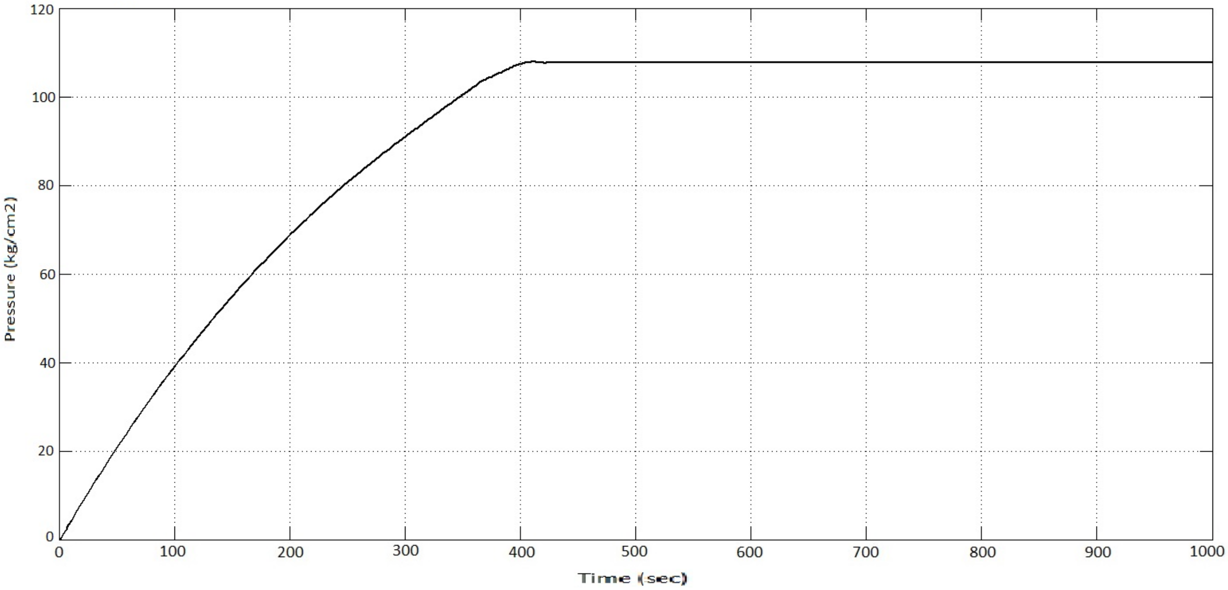


Figure 4.10: Pressure response with fuzzy controller

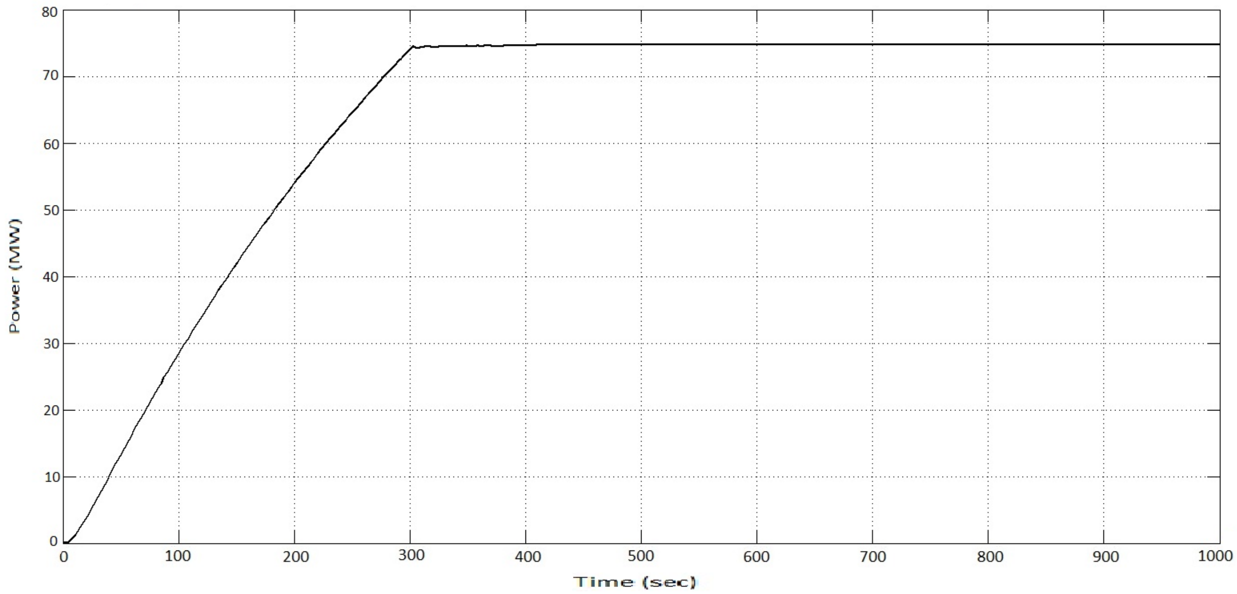


Figure 4.11: Power output response with fuzzy controller

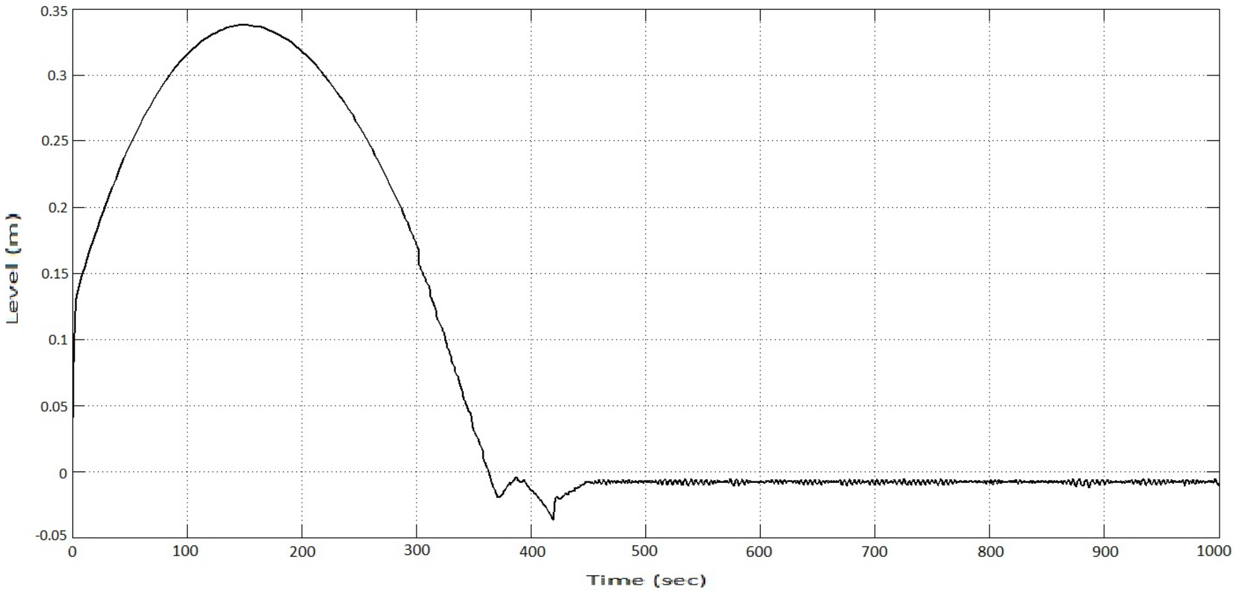


Figure 4.12: Water level response with fuzzy controller

4.5 Comparison and Discussions

In order to validate the control system strategies as described in this study digital simulation were carried out on a converter boiler turbine whose model are given in chapter three. The results of the system under study with PI controller and fuzzy controller are compared with reference. Figure 4.13 shows the compare pressure response, Figure 4.14

shows the compare power output response, and Figure 4.15 shows the compare water level response.

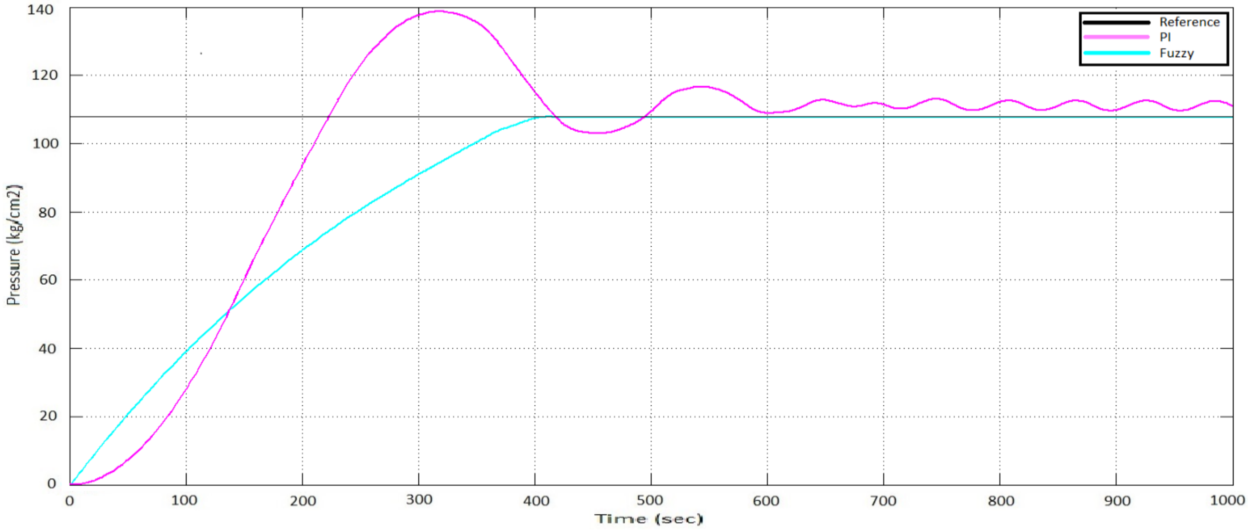


Figure 4.13: Pressure response with PI controller and fuzzy controller

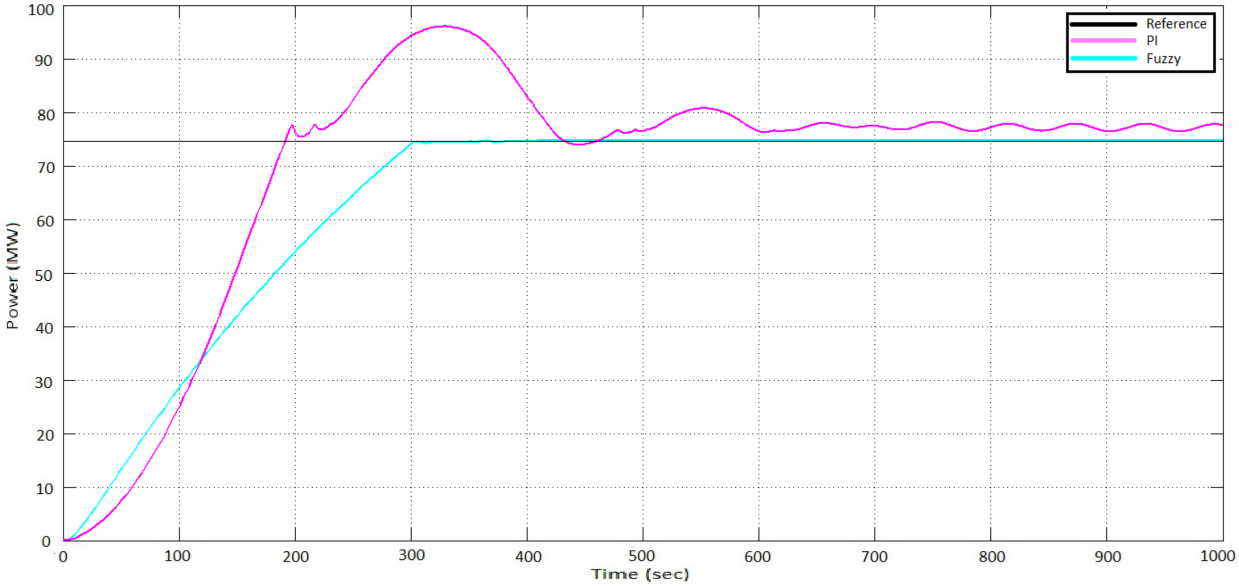


Figure 4.14: Power output response with PI controller and fuzzy controller

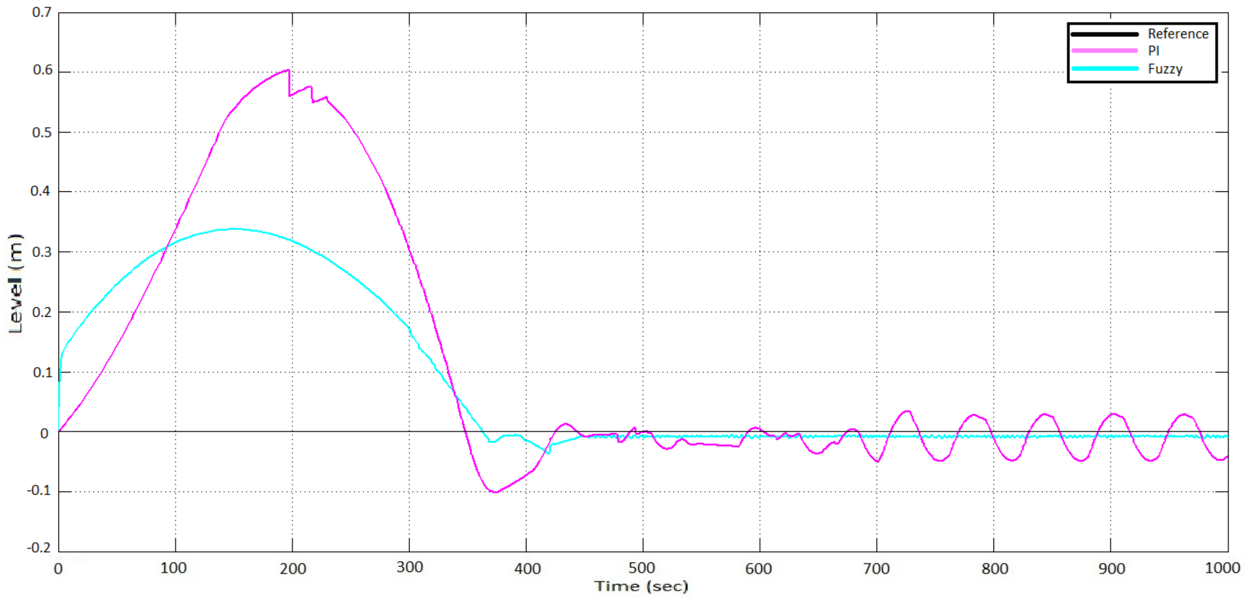


Figure 4.15: Water level response with PI controller and fuzzy controller

First a comparison has been made for drum pressure in terms of rising time, settling time and maximum overshoot between three types of control illustrated in Table 4.1.

Table 4.1: Pressure response comparison

Type of control	Rising time (10%-90%) sec	Settling time sec	Overshoot %
Uncontrolled	144.6	720.17	27.56
PI controller	143.8	541.41	24.37
Fuzzy controller	306.77	394.39	-

Second a comparison has been made for power output in terms of rising time, settling time and maximum overshoot between three types of control illustrated in Table 4.2.

Table 4.2: Power output response comparison

Type of control	Rising time (10%-90%) Sec	Settling time sec	Overshoot %
Uncontrolled	126.31	730.30	24.41
PI controller	124.85	551.75	28.6
Fuzzy controller	231.33	295.71	-

Third a comparison has been made for water level between the maximum values and the error. The results showed in Table 4.3.

Table 4.3 Water level response comparison

Type of control	Maximum Value		Error (m)
	Value (m)	Time (sec)	
Uncontrolled	0.6008	191	0.498
PI controller	0.6041	197.21	0.0491
Fuzzy controller	0.3377	150.6	0.0120

The performance of the system with controllers has been designed are illustrated in figures and tables above contains the controller responses of each one. For both no controller and PI controller the drum pressure is very oscillatory with a large overshoot (27.56%, 24.41) respectively. The response settles out with a steady state error of (4.38, 2.8) kg/$cm2$ for no controller and PI respectively. The drum pressure using fuzzy controller achieved good response there is no oscillating and overshoot with settling time 377.6sec and steady state error 0.33kg/$cm2$.

The power output responses are not good for system in cases PI controller and no controller. But for fuzzy controller the results is good there is no overshoot and achieved settling time 383.72 sec and steady state error 0.14MW. The water level response has high maximum values for no controller and PI controller (0.6m) that can cause shutdown of the boiler. Furthermore in case no controller the error is big. The result of fuzzy controller is acceptable.

CHAPTER FIVE
CONCLUSION AND RECOMMANDATIONS

CHAPTER FIVE

CONCLUSION AND RECOMMANDATIONS

6.1 Conclusion

In this study a fuzzy logic based controller for boiler turbine has been studied. First of all a mathematical model of the system was developed and a conventional PI controller was implemented. The PI controller gave a very high overshoot and high settling time. So an artificial intelligence technique has been proposed and developed. A fuzzy logic controller has been implemented. The result was compared with the conventional controller response. The design of the fuzzy logic controller has been explained and the performance was evaluated. The simulation results indicate that FLC provides the best performance with compared with PI controller, and the shape of the FLC surface is smoother than that of PI controller. In Fuzzy logic control it is not necessary to change the control parameters at any conditions. It is clear that the fuzzy controller is more advantageous than conventional PI because the settling time is short compared with the conventional PI controller. Fuzzy controller gives better dynamic response. This proposed scheme is very suitable for applications of industrial position control drives.

6.2 Recommendations

- To make the control system more efficient, a model of the complete processes with other variables like temperature and air flow rate is needed.
- Apply the system in real time.
- Use of neural networks and genetic algorithm for adjusting fuzzy rules and selecting inputs and outputs membership functions.

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