A Performance Comparison Of PID, FLC & MPC Controller: A Comparative Case Study

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in

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DECLARATION

This is to certify that my work presented in this thesis entitled **"A performance comparison of PID, FLC, & MPC Controller: A Comparative Case Study"** submitted by **Mr. Sachin Agrahari** in partial fulfilment of the requirement for the award of the degree of **Master of Engineering in Electronics Instrumentation and Control Engineering at Thapar University, Patiala.** is an original record under supervision and guidance of **Dr. Yaduvir Singh & Dr. Hardeep Singh**. The matter embodied in this report has not been submitted anywhere for the award of any degree.

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ABSTRACT

This work provides the knowledge about the advance technique like Fuzzy Logic controller technique and MPC, Modal Predictive control technique, to get the better response of the system, when input like unit step input and unit ramp input is applied as the set point of the system. A comparative study is made on the performance of the PID,FLC and MPC controller getting better system parameter like Maximum overshoot(M_p*),Rise time(*t_r*),Peak time(*t_p*) Settling time(*t_s*),Steady state error(*e_{ss}*).Finally a simulation block is made using simulink library browser where all the blocks are given. In the response it is found that settling time, rise time steady state error is less in case of MPC controller rather than PID and FLC controller. Study shows more accurate result using Fuzzy controller over PID controller, further better result got in case of MPC controller.*

ORGANIZATION OF THESIS

Chapter-1 It includes the background information and overview of thesis report.

Chapter-2 This chapter describes the fundamental of boiler is and detailed building blocks of simulation model of three element control.

Chapter-3 Three element control has been elaborated in this chapter.

Chapter-4 Problem formulation and proposed solution with building simulation has been discussed in this chapter.

Chapter-5 This chapter contain analysis of the system with different controller for two inputs.

Chapter-6 The result and discussion has been described in this chapter

Chapter-7 Thesis has been concluded with future scope in this chapter

LIST OF CONTENTS

CONTENTS **PAGE NO.**

LIST OF FIGURES

M. H. DwarakanathEt.al. (1982).They have generalized the methodology for modelling various system components in power system dynamics simulation studies. One of the salient features of the method was its applicability to transient stability, mid-term dynamics simulation and long-term dynamics simulation. Also, the application of sparse matrix techniques to the computation of initial conditions was presented. This method accommodated models of varied degrees of complexity without the need for rewriting or modifying the computer software. The generalized methodology lended itself for implementation in an array processor.

M.Nomura (1988) .He had described a new adaptive optimal control method for boiler steam temperature control of thermal power plants. He has introduced a model of a coal-fired power plant and the automatic plant control (APC) system which assumed to be a single controlled object in order to allow the APC to continue controlling the power plant, even if the adaptive optimal control system fails. Optimal controller gains were calculated using the identified model

B.W.Hogg Et.al. (1990) They had presented an application of generalized predictive control (GPC) to superheat steam pressure of a 200 MW drum boiler. They first used a, single loop PI controllers, but seen that the performance of such controllers is limited since they do not account for variations in the system parameters. Then they used a practical motivation for considering adaptive or self-tuning control. The results shown that substantial improvements in control can be achieved with GPC. Steam pressure variations were greatly reduced, without offsets or overshoot, and with less controller activity. In addition, due to interactions between control loops, there was a significant reduction in variations of steam temperatures and other outputs.

E. Cheres (1990).He had proposed the dynamics of low order boiler models. He had solved the data problem and controller representation for this range. He had presented control schemes field tests, the data problem and the need for accurate low order models representing the boiler dynamics is not new. He then obtained test results and model data, and then introduced parameter uncertainty. The resulted errors due to measurements inaccuracy model simplification and the applied procedure for data evaluation were also presented. The obtained results indicated that simulation and test results were closed as far as typical PI response measures are considered.

Tanaka (1995). In his research he worked on fuzzy identified model, which is a replaced with the plant dynamics. Now the back prorogated error is used for training the controller. Spoone in his paper presented adaptive control technique for non linear system using Lyapunov theory and fuzzy system. But his work was restricted to feedback linearizable plants only.

Hugh F. VanLandingham Et.al.(1996) They had proposed the three element control of boiler by introducing first by PID controller then by Fuzzy controller. This scheme worked satisfactorily in the absence of any process disturbances. They has presented model-free approach in the sense that no plant equations are assumed. Based on this process knowledge, an intelligent control technique, fuzzy logic control (FLC), was developed. They had used simulator to see the response. Intelligent control technique (FLC) is used for the control of drum level in a steam generator boiler system. Better performance compared to the existing 3-element PID control scheme in dealing with the process disturbances.

M. E. Flynn (1997). He has described a drum boiler model developed from first principles and validated using data from tests carried out on an actual plant. The model can be used for dynamic simulation studies in long time frames, greater than 30 seconds, in particular where assessment of deviations of internal parameters, such as steam pressure, drum level and steam temperature, outside safety limits was essential A physically based drum boiler model which runs in real time has been developed and validated using dynamic data recorded on an actual plant. The model will be useful for predicting performance capability while also modelling critical internal variables such as drum level and steam temperatures which may cause the unit to trip if safety limits are violated.

Ollenue (1998).He used the input output linearization method in which outer loop comprised of adaptive fuzzy network. The fuzzy output was used as a supporting input to the adaptive generated output and was used for cancelling the effect of disturbances. The fuzzy structure is determined adaptively in his work. He also described that the liner control feedback law which is used in the inner loop. This approach is not used in the application for the non linear system which are feedback linearizable.

Peter Eserin (June 1999). He has proposed an application of canonical variate analysis (CVA) and 9 element LQG-optimal controls (linear quadratic Gaussian) to boiler drum level control on a 400 kpph gas fired power boiler. He has introduced automated structure selection using CVA simplified selection of input variables for boiler identification, and delivered a useful linear model for optimal control. LQ control technology may be better suited to recovery boilers where the boiler operating load range is narrow and the assumption of linearity were more likely to hold true.. It resulted to be the biggest single impediment to better drum level control.

Donald L. Et.al. (February 2001). They had provided the criteria for design of heating plant instrumentation. The typical saturated-steam power boiler heating plant discussed was operated at a design steam pressure of between 1.03 bar (15 psig) and 20.68 bar (300 psig), with a heating capacity of greater than 422 mega joule/h (400,000 Btu/h). Instrumentation was a rapidly changing field. The options available in choosing and designing plant instrumentation were numerous. A boiler plant includes a large number of instrument items, all of which have to be specified in the procurement of a boiler plant

H. Habbi Et.al. (2003). They proposed fuzzy controller and a fuzzy estimator for a fossil-fuelled drum-type boiler–turbine unit. The fuzzy control method was based on a dynamic Takagi–Sugeno (TS) fuzzy model. For the nonlinear steam power plant. A dynamic fuzzy augmented system was determined to deal with the non-minimum phase behaviour of the plant. To assess the performance of the proposed optimal fuzzy controller, simulations under various operation conditions including actuators saturation are performed over a wide operating range of the physical plant.

Mohanlal (2003). He has revealed a method of exact modelling and optimal control of the inverted pendulum on a cart, which is a benchmark nonlinear dynamic system. Conventionally, the TSK (Takagi-Sugeno-Kang) fuzzy modelling blends local linear models to represent nonlinear system, which in general does not exactly represent the nonlinear system under consideration.

Yongpeng Zhang Et.al.(2004).They have proposed to design digital PID controllers for multivariable systems with time delays. In order to deal with the modelling error owing to the delay time rational approximation, an IMC structure was utilized, such that robust stability could achieved, without need for an observer, and with improved online tuning convenience. Using the prediction-based digital redesign method, the digital implementation was obtained based on the above-proposed analog controller, such that the resulting mixed-signal system performance could closely match that of the analog controlled system.

Min Xu Et.al.(2004).They have proposed a cascade model predictive control scheme for boiler drum level control. They have provided simulink result to show that cascade generalized predictive control results in better performance than that of well tuned cascade proportional integral differential controllers. The algorithm had also been implemented to control a 75-MW boiler plant, and the results showed an improvement over conventional control schemes. The inner loop used an adaptive model based predictive controller, exploiting information conveyed by accessible disturbances, while the outer loop used a GPC controller to restrain the error from nonlinear identification of the generalized system. Based on drum level models, simulation results showed that cascade GPC performed better than the well tuned cascade PID controller, and the performance of the system was very good.

Shaoyuan Li Et.al. (2004) They have proposed a cascade model predictive control scheme for boiler drum level control. They have provided simulink result to show that cascade generalized predictive control results in better performance than that of well tuned cascade proportional integral differential controllers. The inner loop used an adaptive model based predictive controller, exploiting information conveyed by accessible disturbances, while the outer loop used a GPC controller to restrain the error from nonlinear identification of the generalized system. Based on drum level models, simulation results showed that cascade GPC performed better than the well tuned cascade PID controller, and the performance of the system was very good.

Shaoyuan Li.(2005). He has presented the new development of the boiler-turbine coordinated control strategy using fuzzy reasoning and auto tuning techniques. A new coordinated control strategy (CCS) which was organized into two levels: a basic control level and a high supervision level. Gaussian partition with evenly (GPE) spaced midpoints systems, was used to self-tune the main steam pressure PID controller's parameters online based on the error signal and its first difference, aimed at overcoming the uncertainties due to changing fuel calorific value, machine wear, contamination of the boiler heating surfaces and plant modelling errors.

Divnomorskoe.(2005).He has presented a simple method for evaluating process control performance improvements by applying fuzzy conditional probability. The fuzzy conditional probability of an unwanted fuzzy event, while a known disturbance fuzzy event was active, calculated before and after the control improvement. The probability was used as a measurement of the control error. A case study for a boiler control improvement has been presented

Aldo Z. Cipriano (2006). He has introduced about power generation industry which has got experienced significant changes in recent decades Generating plants now also have advanced instrumentation and complex computerized monitoring, supervisory and control systems (Supervisory Control and Data Acquisition, SCADA, or Distributed Control System, DCS).. The exhaust gases from the gas turbine are used to provide heat to the boiler for producing steam, which in turn is fed to the steam turbine.

Yonghong Huang Et.al. (2006).They had proposed about the Adaptive control strategy to regulate the drum-level of a power plant boiler. Based on the three-element feed water control system, recursive least squares method were used to identify the plant parameters and then genetic algorithm (GA) was applied to adjust the parameters of the controller. GA-self-tuned system was able to reject endogenous and exogenous disturbances more effectively and rapidly. GA-self-tuned system was able to reject endogenous and exogenous disturbances more effectively and rapidly, thus had better self-adaptation capability and robustness.

Bordeneuve-Guibe (2007) .Both concerned on the simulation of α-MPC, a robust extension of the initial multivariable predictive control (MPC) law that improves the disturbance-rejection properties of the closed-loop system, reducing the H^{∞}-norm of the multivariable sensitivity function with an extra parameter. First they introduced the original MPC, and then they described the extended α-MPC algorithm and analyzed the robustness of the closed-loop system through the H^{∞} approach. The methodology of the control design task and experimental test stand, focusing on the software and hardware implementation are described. Finally, they reported the results of the α-MPC control law on the actual test stand.

Rosehart, W (2008).He proposed on the large load occurred on the process. when large load caused by trips and start ups of steam consuming processes. Pressure stability of the plant must be maintained .The required stability is achieved by using load levelling components for balancing the loads in the steam network. In large scale systems the dynamic simulation is the only possibility to analyze the responses caused by the disturbances and design the process and control system to meet the requirements set for the plant.

CHAPTER 1
INTRODUCTION

1.1 Overview

Boiler is a closed vessel in which water or other fluid is heated. All of these types can generate hot water or steam by absorbing heat from another fluid. The heated or vaporized fluid exits the boiler for use in various processes or heating applications. A boiler or steam generator is employed wherever a source of steam is required. Portable engines and steam-powered road vehicles typically use a smaller boiler that forms an integral part of the vehicle.

Boilers were a source of many serious injuries and property destruction due to poorly understood engineering principles .A boiler that has a loss of feed water and is permitted to boil dry can be extremely dangerous. If feed water is then sent into the empty boiler, the small cascade of incoming water instantly boils on contact with the superheated metal shell and leads to a violent explosion that cannot be controlled even by safety steam valves replaced. Various controlling mechanism are used to control the system so that it works properly.

Draining of the boiler could also occur if a leak occurred in the steam supply lines that were larger than the make-up water supply could replace.

1.2 Three Element Control

In the process industries, for the proper functioning of boiler we use to control the three elements as steam out flow, level of fluid, and feed water flow. Pressure, temperature and level cannot be controlled; the only thing that can be controlled is flow. The pressure or temperature in a boiler is maintained by controlling the flow of fuel and air. Also, the level is maintained by controlling the flow of feed water. Pressure, temperature, level, and other measures will increase or decrease only with a change in flow. The purpose of the drum level controller is to bring the drum up to level at boiler start-up and maintain the level at constant steam load. In single element control, a drum level measurement and a feed water control valve is required. The Two-Element Drum Level Control uses two variables, drum level and steam flow to manipulate the feed water control valve. The three-Element Drum Level Control uses three variables, drum level and steam flow and feed water flow rate, to manipulate the feed water control valve.

1.3 Applications

Boilers have many applications.

- 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 (steam wagons) based on their high-pressure vertical boilers

1.4 Control Strategies

Control strategies are necessary for any system to perform accurately some of these are given below:

1.4.1 PID Controller

For the drum level control, a 3-element proportional-integral-derivative (PID) control is popular conventional approach. It works satisfactorily in the absence of any process disturbances. However, when there are significant process disturbances, the 3-element PID control scheme does not perform well because of lack of knowledge of proper controller gains to cope with such disturbances. Inevitably over time and use, PID controllers get detuned.

1.4.2 Fuzzy Logic Controller

A new technique came into existence .Based on the process knowledge, an intelligent control technique, fuzzy logic control (FLC), is developed. First rule base is made then embed it into the controller. The technique proposed in this was tested on a process simulator. It give better response than PID.

1.4.3 MPC Controller

Model predictive controllers rely on dynamic models of the process, most often linear empirical models obtained by system identification. This model is determined to depict the behaviour of complex dynamical systems. The models shall compensate for the impact of non-linearities of variables and the chasm caused by non coherent process devolution. It uses an internal dynamic model of the process, a history of past control moves and an optimization cost function J over the receding prediction horizon, to calculate the optimum control moves.

1.5 Structure of proposed system

To analyse the behaviour of system to control three elements of boiler, a simulink modal is designed. In that various blocks are attached such as IMC controller which works as primary controller, saturation block, transfer function block, step block ramp block,Mux block etc.PID controller block, Fuzzy controller block and MPC controller block work as primary controller. Step input and Ramp input are given to analyse the system behaviour.

CHAPTER 2

FUNDAMENTALS OF BOILER & BLOCKS

2.1 Introduction

Boiler is a closed vessel in which water or other fluid is heated. It do not have to have a burner. All of these types can generate hot water or steam by absorbing heat from another fluid. That other fluid can be steam and create steam or hot water, it can be HTHW and generate steam, or it can be a hot liquid or gas from some chemical process that is hot enough to do the job. One of the largest low pressure steam boilers that was ever built in the late 1960's and it generated steam by oxidizing a liquid. The heat source was a large volume of oil which air was forced through to oxidize the liquid similar to combustion but at a low temperature and nowhere near complete combustion. Twenty four feet in diameter and ninety feet tall with thousands of square feet of heating surface it made about 25,000 pounds per hour.

Other projects included a hot water boiler using 500°F air from a steelmaking operation rated at 100 million Btuh. Operating that type of equipment to get the most steam out of it is wise because you save on fuel that would have to be used to generate that steam. These boilers can be constructed as unfired pressure vessels in accordance with Section VIII of the ASME Code, "Rules for Construction of Pressure Vessels." Boilers that are fired must be built to Section I or Section IV but their construction is limited to materials that can handle the high rates of heat transfer required for direct fired equipment. Boilers using waste heat can require materials of construction that can't handle direct firing but are essential to prevent corrosion in the waste heat application. In simpler words, a fired boiler can't be built in stainless steel, an unfired boiler can be. Since there's a fixed relationship between pressure and temperature for steam and water, pressure has to increase. To heat product or other materials to high temperatures, pressures may get very high. To obtain temperatures greater than about 500°.

Equipment that heats water in an open container or very small one is not a boiler. Our teapot doesn't have to be constructed in accordance with the code because it's so small. The hot water heater in our home isn't considered a boiler unless it holds more than 120 gallons. Another limit on the size of a boiler is an internal diameter of 6 inches or less. The exceptions found in the code are occasionally stretched to create boilers that, by definition, are not. Fired air heaters are not boilers unless the air is under pressure. Any application that heats air or any other gas for that matter, that doesn't contain the heated fluid in an enclosed vessel, is normally called a furnace. If the fluid is air or another gas and it's under pressure then it does meet the definition of a boiler. There are many boilers unique to their respective industry. Asphalt heaters, flux heaters (a raw material that becomes asphalt), many forms of waste heat boilers and equipment like recovery boilers (used in the paper industry) which convert product can be encountered by burning it. The principles discussed here will allow understanding those unique boilers which, by virtue of their uniqueness, are best understood by reading the operating and maintenance instruction manuals for them. This section contains general descriptions of the basic elements of a boiler plant to provide a basic understanding of the systems and equipment.

2.2 Boiler

It is a closed vessel in which water or other fluid is heated. The heated or vaporized fluid exits the boiler for use in various processes or heating applications. It is a device used to create steam by applying heat energy to water. Although the definitions are somewhat flexible, it can be said that older steam generators were commonly termed boilers and worked at low to medium pressure (1-300 psi), but at pressures above that figure it is more usual to speak of a steam generator.

Figure 2.1 An industrial boiler

A boiler or steam generator is employed wherever a source of steam is required. The form and size depends on the application: mobile steam engines such as steam locomotives, portable engines and steam-powered road vehicles typically use a smaller boiler that forms an integral part of the vehicle; stationary steam engines, industrial installations and power stations will usually have a larger separate steam generating facility connected to the point-of-use by piping. A notable exception is the steam-powered fireless locomotive, where separately-generated steam is transferred to a receiver (tank) on the locomotive.

2.3 Types of Boiler: There are various types of boilers use in the industries; some of these are given below

2.3.1 Pot boiler

Pot boiler is also called as "Haycock boiler": a primitive "kettle" where a fire heats a partially-filled water container from below. 18th Century Haycock boilers generally produced and stored large volumes of very low-pressure steam, often hardly above that of the atmosphere. These could burn wood or most often, coal. Efficiency was very low.

2.3.2 Fire-tube boiler

Here, water partially fills a boiler barrel with a small volume left above to accommodate the steam (steam space). This is the type of boiler used in nearly all steam locomotives. The heat source is inside a furnace or firebox that has to be kept permanently surrounded by the water in order to maintain the temperature of the heating surface just below boiling point. The furnace can be situated at one end of a fire-tube which lengthens the path of the hot gases, thus augmenting the heating surface which can be further increased by making the gases reverse direction through a second parallel tube or a bundle of multiple tubes (two-pass or return flue boiler); alternatively the gases may be taken along the sides and then beneath the boiler through flues (3-pass boiler). In the case of a locomotive-type boiler, a boiler barrel extends from the firebox and the hot gases pass through a bundle of fire tubes inside the barrel which greatly increase the heating surface compared to a single tube and further improve heat transfer. Fire-tube boilers usually have a comparatively low rate of steam production, but high steam storage capacity. Fire-tube boilers mostly burn solid fuels.

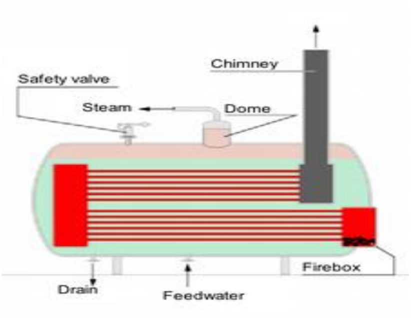


Figure 2.2 Diagram of a fire-tube boiler

2.3.3 Water-tube boiler

In this type, the water tubes are arranged inside a furnace in a number of possible configurations: often the water tubes connect large drums, the lower ones containing water and the upper ones, steam and water; in other cases, such as a monotube boiler, water is circulated by a pump through a succession of coils. This type generally gives high steam production rates, but less storage capacity than the above. Water tube boilers can be designed to exploit any heat source and are generally preferred in high pressure applications since the high pressure water/steam is contained within small diameter pipes which can withstand the pressure with a thinner wall.

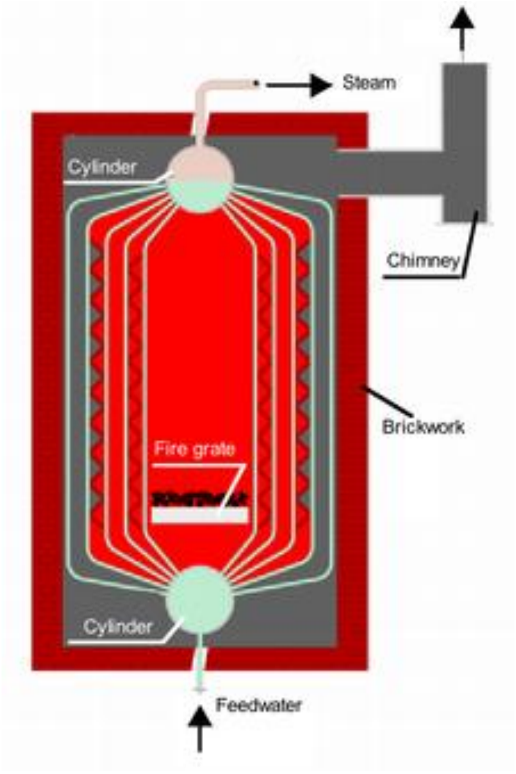


Figure 2.3 Diagram of a water-tube boiler

2.3.4 Flash boiler

It is a type of water-tube boiler, whose tubes are strong and close together with water pumped through the tubes. The tubes are kept very hot so the water feed is quickly flashed into steam and superheated. They have these advantages:

- Less weight and bulk.
- Less time to raise steam from cold.

A flash boiler is much easier than an ordinary boiler to overheat, as there is no large reservoir of water to keep the tubes from high temperature if the water flow is interrupted or inadequate.

2.3.5 Sectional boiler

In a cast iron sectional boiler, sometimes called a "pork chop boiler" the water is contained inside cast iron sections. These sections are assembled on site to create the finished boiler.

2.3.6 Multi tube boiler

A significant step forward came in France in 1828 when Marc Seguin devised a two-pass boiler of which the second pass was formed by a bundle of multiple tubes. A similar design with natural induction used for marine purposes was the popular “Scotch” marine boiler.

Prior to the Rainhill trials of 1829 Henry Booth, treasurer of the Liverpool and Manchester Railway suggested to George Stephenson, a scheme for a multi-tube one-pass horizontal boiler made up of two units: a firebox surrounded by water spaces and a boiler barrel consisting of two telescopic rings inside which were mounted 25 copper tubes; the tube bundle occupied much of the water space in the barrel and vastly improved heat transfer. Old George immediately communicated the scheme to his son Robert and this was the boiler used on Stephenson’s Rocket, outright winner of the trial. The design was and formed the basis for all subsequent Stephensonian-built locomotives, being immediately taken up by other constructors; this pattern of fire-tube boiler has been built ever since.

2.3.7 Superheated steam boilers

Most boilers heat water until it boils, and then the steam is used at saturation temperature (i.e., saturated steam). Superheated steam boilers boil the water and then further heat the steam in a super heater. This provides steam at much higher temperature, but can decrease the overall thermal efficiency of the steam generating plant due to the fact that the higher steam temperature requires a higher flue gas exhaust temperature. There are several ways to circumvent this problem, typically by providing a feed water heating "economizer", and/or a combustion air heater in the hot flue gas exhaust path. There are advantages to superheated steam and this may (and usually will) increase overall efficiency of both steam generation and its utilisation considered together: gains in input temperature to a turbine should outweigh any cost in additional boiler complication and expense. There may also be practical limitations in using "wet" steam, as causing condensation droplets will damage turbine blades.

Superheated steam presents unique safety concerns because, if there is a leak in the steam piping, steam at such high pressure/temperature can cause serious, instantaneous harm to anyone entering its flow. Since the escaping steam will initially be completely superheated vapour, it is not easy to see the leak, although the intense heat and sound from such a leak clearly indicates its presence.

The super heater works like coils on an air conditioning unit, however to a different end. The steam piping (with steam flowing through it) is directed through the flue gas path in the boiler furnace. This area typically is between 1,300 °C (2,372 °F)-1,600 °C (2,912 °F). Some super heaters are radiant type (absorb heat by radiation), others are convection type (absorb heat via a fluid i.e. gas) and some are a combination of the two. So whether by convection or radiation the extreme heat in the boiler furnace/flue gas path will also heat the super heater steam piping and the steam within as well. It is important to note that while the temperature of the steam in the superheater is raised, the pressure of the steam is not: the turbine or moving pistons offer a "continuously expanding space" and the pressure remains the same as that of the boiler. The process of superheating steam is most importantly designed to remove all droplets entrained in the steam to prevent damage to the turbine blading and/or associated piping.

2.3.8 Hydronic boilers

Hydronic boilers are used in generating heat for residential and industrial purposes. They are the typical power plant for central heating systems fitted to houses in northern Europe (where they are commonly combined with domestic water heating), as opposed to the forced-air furnaces or wood burning stoves more common in North America. The hydronic boiler operates by way of heating water/fluid to a preset temperature (or sometimes in the case of single pipe systems, until it boils and turns to steam) and circulating that fluid throughout the home typically by way of radiators, baseboard heaters or through the floors. The fluid can be heated by any means...gas, wood, fuel oil, etc, but in built-up areas where piped gas is available, natural gas is currently the most economical and therefore the usual choice. The fluid is in an enclosed system and circulated throughout by means of a motorized pump. The name can be a misnomer in that, except for systems using steam radiators, the water in a properly functioning hydronic boiler never actually boils. Most new systems are fitted with condensing boilers for greater efficiency. These boilers are referred to as condensing boilers because they condense the water vapour in the flue gases to capture the latent heat of vaporization of the water produced during combustion.

Hydronic systems are being used more and more in new construction in North America for several reasons. Among the reasons are:

- They are more efficient and more economical than forced-air systems (although initial installation can be more expensive, because of the cost of the copper and aluminium).
- The baseboard copper pipes and aluminium fins take up less room and use less metal than the bulky steel ductwork required for forced-air systems.
- They provide more even, less fluctuating temperatures than forced-air systems. The copper baseboard pipes hold and release heat over a longer period of time than air does, so the furnace does not have to switch off and on as much. (Copper heats mostly through conduction and radiation, whereas forced-air heats mostly through forced convection. Air has much lower thermal conductivity and higher specific heat than copper; however, convection results in faster heat loss of air compared to copper. See also thermal mass.)
- They do not dry out the interior air as much.
- They do not introduce any dust, allergens, mold, or (in the case of a faulty heat exchanger) combustion by-products into the living space.

Forced-air heating does have some advantages, however.

2.4 Material

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 the 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 Cleator Moor (UK), 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. The brittleness of cast iron makes it impractical for high pressure steam boilers.

2.5 Fuel

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 (HRSGs) use the heat rejected from other processes such as gas turbines

2.6 Safety

Historically, boilers were a source of many serious injuries and property destruction due to poorly understood engineering principles. Thin and brittle metal shells can rupture, while poorly welded or riveted seams could open up, leading to a violent eruption of the pressurized steam. Collapsed or dislodged boiler tubes could also spray scalding-hot steam and smoke out of the air intake and firing chute, injuring the firemen who loaded coal into the fire chamber. Extremely large boilers providing hundreds of horsepower to operate factories could demolish entire buildings.

A boiler that has a loss of feed water and is permitted to boil dry can be extremely dangerous. If feed water is then sent into the empty boiler, the small cascade of incoming water instantly boils on contact with the superheated metal shell and leads to a violent explosion that cannot be controlled even by safety steam valves. Draining of the boiler could also occur if a leak occurred in the steam supply lines that were larger than the make-up water supply could replace. The *Hartford Loop* was invented in 1919 by the Hartford Steam Boiler and Insurance Company as a method to help prevent this condition from occurring, and thereby reduce their insurance claims.

2.7 Flow

One can’t control pressure, temperature, level the only thing which we can control is flow. The pressure or temperature is maintained in a boiler by controlling the flow of fuel and air.

Level is maintained by controlling the flow of feed water. Pressure, temperature, level, and other measures will increase or decrease only with a change in flow. An increase in flow will increase decrease the value that are measuring depending on the direction of the flow. It's a fundamental that, once grasped, will always serve an operator in determining the cause of, and solution to, a problem with control. Read that first paragraph again and think about your boiler operation and eventually understand it. There's absolutely no way for to grab a pressure, temperature, or level and change it. For changing those measures always involves a change in flow. There are two means for controlling flow. Turn it on and off or can vary the flow rate. When the flow rate is changing it called as "modulating" and the method is called "modulation." To restore the level in a chemical feed tank valve, is opened and shut it when the level is near the top, and chemicals is added to restore the concentration; that's on-off control. A float valve on a make-up water tank opens as the level drops to increase water flow and closes to decrease flow as the level rises; that's modulation.

The energy in the steam leaving the boiler plant requires energy enter the plant in the form of fuel flow. If the steam leaving contains more energy than is supplied by the fuel entering then the steam pressure will fall. Some of the energy in the fuel ends up in the flue gases going up the stack so the energy in the fuel has to match the sum of the energy lost up the stack and leaving in the steam. The sum of everything flowing into the boiler plant has to match what is flowing out or plant conditions will change. The fuel in the furnace of a boiler burns at temperatures in the range of 1200 to 3200°F which is usually more than enough to keep it burning and heat up any new fuel that's added to the fire. Modern furnaces, however, are almost entirely composed of water-cooled walls which absorb most of the radiant heat of the fire. Despite that high temperature a fire in a modern boiler is barely holding on and it doesn't take much to put it out.

2.8 Description of Model

The simulation model and its various parts has been described in detail as under.

2.8.1 Mux Block

Combine several input signals into vector. The Mux block combines its inputs into a single vector output. An input can be a scalar or vector signal. All inputs should be of the same data type and numeric type. The elements of the vector output signal take their order from the top to bottom, or left to right, input port signals.

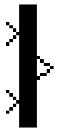


Figure 2.4 Block diagram of MUX

The Mux block allows you to connect signals of differing data and numeric types and matrix signals to its inputs. In this case, the Mux block outputs bus signal combining the inputs. In other words, the Mux block behaves like a Bus Creator block. Nevertheless, you should use Bus Creator blocks in such cases to ensure that your model will run in future releases of Simulink, which may not support the use of Mux blocks as Bus Creators. If your model currently uses Mux blocks as Bus Creators, you may want to consider replacing the Mux blocks with equivalent Bus Creator blocks .The Mux block's Number of Inputs parameter allows you to specify input signal names and sizes as well as the number of inputs. We can use any of the following formats to specify this parameter: Scalar specifies the number of inputs to the Mux block. When this format is used, the block accepts scalar or vector signals of any size. Simulink assigns each input the name signal N, where N is the input port number. Vector The length of the vector specifies the number of inputs. Each element specifies the size of the corresponding input. A positive value specifies that the corresponding port can accept only vectors of that size. . If an input signal width does not match the expected width, Simulink displays an error message. A value of -1 specifies that the corresponding port can accept scalars or a vector of any size. Cell array the length of the cell array specifies the number of inputs. The value of each cell specifies the size of the corresponding input.

A scalar value N specifies a vector of size N. A value of -1 means that the corresponding port can accept scalar or vector signals of any size. Signal name list you can enter a list of signal names separated by commas. Simulink assigns each name to the corresponding port and signal. For example, if you enter position, velocity, the Mux block will have two inputs, named position and velocity. Simulink hides the name of a Mux block when you copy it from the Simulink block library to a model. Data Type Support the Mux block accepts real or complex signals of any data type supported by Simulink, including fixed-point data types. For a discussion on the data types supported by Simulink.

2.8.2 Scope Block

The Scope block displays its input with respect to simulation time. The Scope block can have multiple axes (one per port); all axes have a common time range with independent y-axes. The Scope allows you to adjust the amount of time and the range of input values displayed. You can move and resize the Scope window and you can modify the Scope's parameter values during the simulation. When you start a simulation, Simulink does not open Scope windows, although it does write data to connected Scopes. As a result, if you open a Scope after a simulation, the Scope's input signal or signals will be displayed. If the signal is continuous, the Scope produces a point-to-point plot. If the signal is discrete, the Scope produces a stair-step plot. The Scope provides toolbar buttons that enable you to zoom in on displayed data, display all the data input to the Scope, preserve axis settings from one simulation to the next, limit data displayed, and save data to the workspace. The toolbar buttons are labeled in this figure, which shows the Scope window as it appears when you open a Scope block.

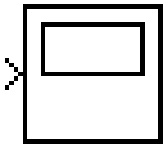


Figure 2.5 Block diagram of scope

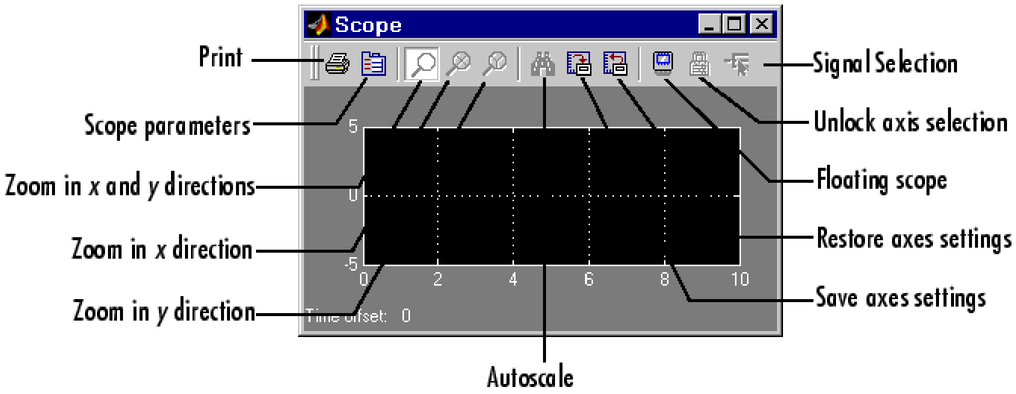


Figure 2.6 Scope window

2.8.3 Saturation Block

The Saturation block imposes upper and lower bounds on a signal. When the input signal is within the range specified by the Lower limit and Upper limit parameters, the input signal passes through unchanged. When the input signal is outside these bounds, the signal is clipped to the upper or lower bound. When the Lower limit and Upper limit parameters are set to the same value, the block outputs that value. Data Type Support The Saturation block accepts real signals of any data type supported by Simulink, except Boolean. The Saturation block supports fixed-point data types. The output data type is the same as the input data type. For a discussion on the data types supported by Simulink.

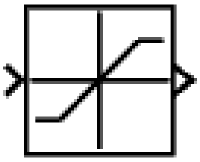


Figure 2.7 Block diagram of saturation

Upper limit Specify the upper bound on the input signal. When the input signal to the Saturation block is above this value, the output of the block is clipped to this value. The Upper limit parameter is converted to the input data type offline using round-to-nearest and saturation. Lower limit Specify the lower bound on the input signal. When the input signal to the Saturation block is below this value, the output of the block is clipped to this value. The Lower limit parameter is converted to the input data type offline using round-to-nearest and saturation.

2.8.4 Transfer Function Block

The Transfer Function block models a linear system by a transfer function of the Laplace-domain variable s. The block can model both single-input single-output (SISO) and single-input multiple output (SIMO) systems.

$$H(s) = \frac{y(s)}{u(s)} = \frac{num(s)}{den(s)} = \frac{num(1)s^{nn-1} + num(2)s^{nn-2} + \ldots + num(nn)}{den(1)s^{nd-1} + den(2)s^{nd-2} + \ldots + den(nd)} \qquad (1)$$

This block assumes that the transfer function has the following form where u and y are the system's input and outputs, respectively, nn and nd are the number of numerator and denominator coefficients, respectively. num and den contain the coefficients of the numerator and denominator in descending powers of s.The order of the denominator must be greater than or equal to the order of the numerator. This block also assumes that the transfer functions for the outputs of a multiple output system have the same denominator and that the numerators of the transfer functions have the same order. To model a single-output system, enter a vector containing the system transfer function's numeric coefficients in the Numerator coefficient field in the block's parameter dialog box. Enter a vector containing the transfer function's denominator coefficients in the Denominator coefficient field. In this case, the input and output of the block are scalar time-domain signals. To model a multiple-output system, enter a matrix in the Numerator coefficient field where each row of the matrix contains the numerator coefficients of a transfer function that determines one of the block's outputs. Enter a vector containing the denominator coefficients common to the system's transfer functions in the Denominator coefficient field. In this case, the block's input is a scalar and the block's output is a vector.

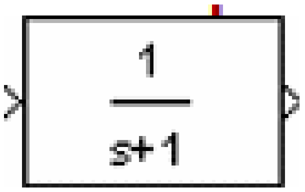


Figure 2.8 Block diagram of Transfer Fn.

2.8.5 Step Block

The Step block provides a step between two definable levels at a specified time. If the simulation time is less than the Step time parameter value, the block's output is the Initial value parameter value. For simulation time greater than or equal to the Step time, the output is the Final value parameter value. The block's numeric parameters must be of the same dimensions after scalar expansion. If the Interpret vector parameters as 1-D option are off, the block outputs a signal of the same dimensions and dimensionality as the parameters. If the Interpret vector parameters as 1-D option is on and the numeric parameters are row or column vectors (i.e., single row or column 2-D arrays), the block outputs a vector (1-D array) signal; otherwise, the block outputs a signal of the same dimensionality and dimensions as the parameters.

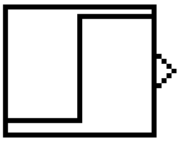
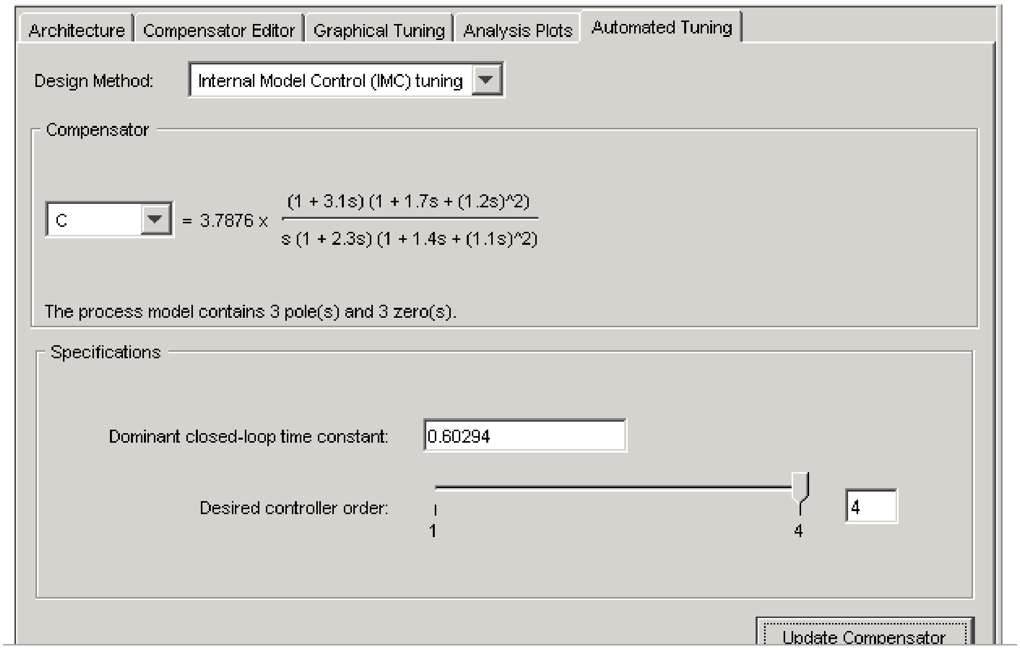


Figure 2.9 Block diagram of Step Fn.

2.8.6 IMC Tuning

IMC design generates a full-order feedback controller that guarantees closed-loop stability when there is no model error and the plant is stable. It also contains an integrator, which guarantees zero steady-state offset for plants without a free differentiator.

The parameter relates directly to the closed loop speed of response and the robustness of the control loop. For a system with dead time, if used as an approximation for the time delay, the IMC controller includes implicitly integral action and has a PID structure in cascade with a filter. Internal model control (IMC) tuning (note that this is different from selecting Internal Model Control (IMC) tuning as the full automated tuning method.



Design Method: Internal Model Control (IMC) tuning

Compensator

C = 3.7876 x (1 + 3.1s) (1 + 1.7s + (1.2s)^2) / s (1 + 2.3s) (1 + 1.4s + (1.1s)^2)

The process model contains 3 pole(s) and 3 zero(s).

Specifications

Dominant closed-loop time constant: 0.60294

Desired controller order: 4

Figure 2.10 IMC parameters block

Follow these steps to design an IMC controller.

- Specify a Dominant closed-loop time constant.
- The initial value is set as 5% of the open-loop settling time. In general, increasing this value slows down the closed system and makes it more robust.
- Specify the Desired controller order using the slider. After you obtain a full-order feedback controller, you can try to reduce its order. You may lose performance and closed-loop stability if you reduce the order.

2.8.7 Fuzzy Logic Controller

FLC incorporates a simple, rule-based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically. The FLC model is empirically-based, relying on an operator's experience rather than their technical understanding of the system. For example, rather than dealing with temperature control in terms such as "SP =500F", "T <1000F", or "210C <TEMP <220C", terms like "IF (process is too cool) AND (process is getting colder) THEN (add heat to the process)" or "IF (process is too hot) AND (process is heating rapidly) THEN (cool the process quickly)" are used. These terms are imprecise and yet very descriptive of what must actually happen. Consider what you do in the shower if the temperature is too cold, you will make the water comfortable very quickly with little trouble. FLC is capable of mimicking this type of behaviour but at very high rate. Block diagram of fuzzy controller is given as under. The Fuzzy Logic Controller block implements a fuzzy inference system.

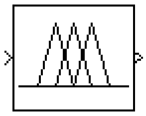


Figure 2.11 Block diagram of fuzzy controller

After making the appropriate rules for the controller to work it is then saved in the under shown dialog box.

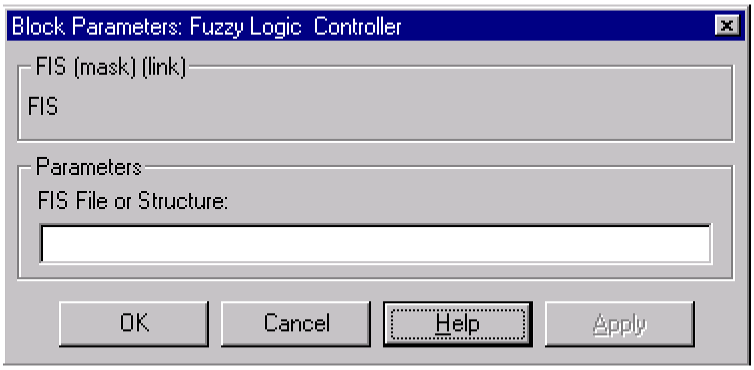


Figure 2.12 Block parameters

To open the dialog box for the Fuzzy Logic Controller (with or without the Rule Viewer), double-click the block. Enter the name of the structure variable describing your FIS. This variable must be located in the MATLAB workspace. If the fuzzy inference system has multiple inputs, these inputs should be multiplexed together before feeding them into either the Fuzzy Logic Controller or the Fuzzy Logic Controller with Rule Viewer block. Similarly, if the system has multiple outputs, these signals will be passed out of the block on one multiplexed line.

(FLS) is the building block in most systems incorporating fuzzy logic. An FLC can be implemented in the form of an FLS. One form of an FLC consists of a fuzzifier, a rule base, an inference engine and a defuzzifier.First rule is made according to desired output then it is save in the above FIS file.

CHAPTER 3

THREE ELEMENT CONTROL

3.1 Introduction

In the process industries, for the proper functioning of boiler the three elements which is controlled are steam out flow, level of fluid, and feed water flow. Pressure cannot be controlled, Temperature cannot be controlled and also level cannot be controlled the only thing that can be control is flow. The pressure or temperature in a boiler is maintained by controlling the flow of fuel and air. The level is maintained by controlling the flow of feed water. Pressure, temperature, level, and other measures will increase or decrease only with a change in flow. An increase in flow will increase decrease the value we’re measuring depending on the direction of the flow.. It always brings a frown to the operator’s face.

There’s absolutely no way to grab a pressure, temperature, or level and change it. Any description can come with for changing those measures always involves a change in flow. We have two means for controlling flow. It can turn on and off or it can vary the flow rate. When changing the flow rate we call it “modulating” and the method is called “modulation.” To restore the level in a chemical feed tank you open a valve, shut it when the level is near the top, and you add chemicals to restore the concentration; that’s on-off control. A float valve on a make-up water tank opens as the level drops to increase water flow and closes to decrease flow as the level rises; that’s modulation. The energy in the steam leaving the boiler plant requires energy enter the plant in the form of fuel flow. If the steam leaving contains more energy than is supplied by the fuel entering then the steam pressure will fall. Some of the energy in the fuel ends up in the flue gases going up the stack so the energy in the fuel has to match the sum of the energy lost up the stack and leaving in the steam. The sum of everything flowing into the boiler plant has to match what is flowing out or plant conditions will change. The fuel in the furnace of a boiler burns at temperatures in the range of 1200 to 3200°F which is usually more than enough to keep it burning and heat up any new fuel that’s added to the fire. Modern furnaces, however, are almost entirely composed of water-cooled walls which absorb most of the radiant heat of the fire. Despite that high temperature a fire in a modern boiler is barely holding on and it doesn’t take much to put it out.

3.2 Boiler Drum Level Control

Boiler drum level control is critical for both plant protection and equipment safety and applies equally to high and low levels of water within the boiler drum. The purpose of the drum level controller is to bring the drum up to level at boiler start-up and maintain the level at constant steam load. A dramatic decrease in this level at constant steam load. A dramatic decrease in this level may uncover boiler tubes, allowing them to become overheated and damaged. An increase in this level may interfere with the process of separating moisture from steam within the drum, thus reducing boiler efficiency and carrying moisture into the process or turbine. Typically there are three strategies used to control drum level, with each successive strategy a refinement of the previous strategy. The recommended strategy depends on the measurement and control equipment available and the extent of the load change requirements.

The functions of this control models can be broken down into the following

- Operator adjustment of the set point for drum level
- Compensation for the *shrink & swell* effects
- Automatic control of drum level
- Manual control of the feed water valve
- Bump-less transfer between auto and manual modes
- Indication of drum level and steam flow
- Indication of feed water valve position and feed water flow
- Absolute/deviation alarms for drum level

The Three main options available for drum level control are:

3.2.1 Single element drums level control:

The simplest but least effective form of drum level control is the single element control. It requires a drum level measurement and a feed water control valve. It is typical in fire tube boilers and is recommended for boilers with modest load change requirements and relatively constant feed water conditions. This consists of proportional signal or process variable (PV) coming from the drum level transmitter. This signal is compared to a set point and the difference is a deviation value. This signal is acted upon by the controller which generates corrective action in the form of a proportional output. The output is then passed to the boiler feed water valve, which then adjusts the level of feed water flow into the boiler drum

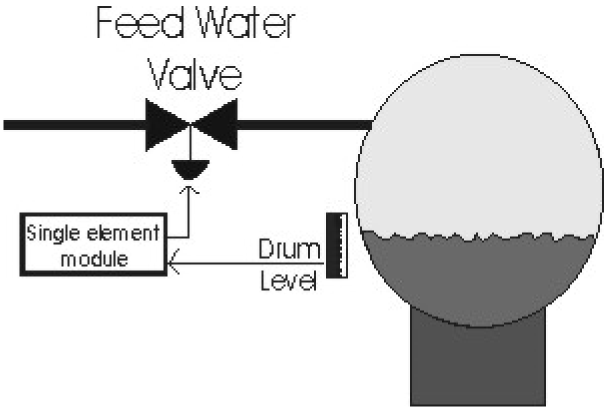


Figure 3.1 Single element control

Some points are to be noted:

- Only one analogue input and one analogue output required
- Can only be applied to single boiler / single feed pump configurations with relatively stable loads since there is no relationship between drum level and steam- or feed water flow.
- Possible inadequate control option because of the *swell* effect.

3.2.2 Two element drum level control

The two-element drum level controller can best be applied to a single drum boiler where the feed water is at a constant pressure. It requires drum level measurement, load demand measurement and feed water valve control. The load demand change is typically inferred from the steam flow rate measurement. This strategy is recommended for boiler applications with moderate load change requirements. Drum water level is affected by the firing rate of the burner. The higher the firing rate, the more water vapour bubbles are formed in the water phase, causing the water volume to expand. This effect is most noticeable during firing rate changes. It is known as swell, and the opposite effect is known as shrink. Single element control does not handle this phenomenon well. is suitable for processes with moderate load swings and can be used on any size boiler. The Two-Element Drum Level Control uses two variables, drum level and steam flow to manipulate the feed water control valve. Steam flow load changes are fed forward to the feed water control valve providing an initial correction for the load changes. The steam flow range and feed water flow range are matched so that a one pound change in steam flow results in a one pound change in feed water flow.

The summer combines the steam flow signal with the feedback action of the drum level controller which makes trim adjustments in feed water flow, as required, to compensate for unmeasured blow down losses and steam flow measurement errors. The UDC 3500 can be placed into Manual mode to permit manual control of the feed water valve. Two-element control is adequate for load changes of moderate speed and magnitude, and it can be applied to any size boiler. It has two drawbacks which must be considered. It cannot adjust for pressure or load disturbances in the feed water system and it cannot eliminate phasing interaction between the various portions of process because only the relatively slow responding drum level is controlled. If these disturbances are a concern, than three-element drum level control an correct the drawbacks

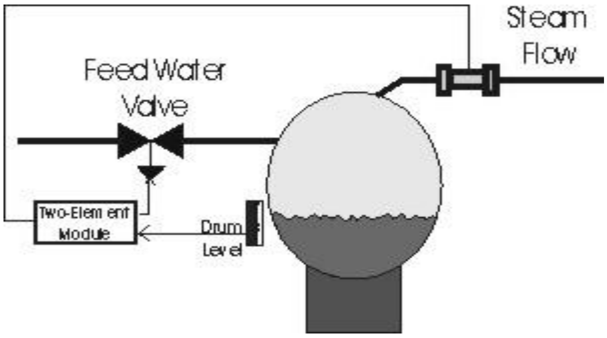


Figure 3.2 Two element control

The two elements are made up of the following:

Level Element: A proportional signal or process variable (PV) coming from the drum level transmitter. This signal is compared to a set point and the resultant is a deviation value. This signal is acted upon by the controller which generates corrective action in the form of a proportional value.

Steam Flow Element: A mass flow rate signal (corrected for density) is used to control the feed water flow, giving immediate corrections to feed water demand in response to load changes.

Any imbalance between steam mass flow out and feed water mass flow into the drum is corrected by the level controller.

This imbalance can arise from

- Blow down variations due to changes in dissolved solids
- Variations in feed water supply pressure
- Leaks in the steam circuits.

Some points are to be noted:

- Tighter control of drum level than with only one element
- Steam flow act as feed forward signal to allow faster level adjustments

- Can best be applied to single boiler / single feed pump configurations with a constant feed water pressure

3.2.3 Three-element drum level control:

The three-element drum level control is ideally suited where a boiler plant consists of multiple boilers and multiple feed water pumps or where the feed water has variations in pressure or flow. It adds a third variable, feed water flow rate, to manipulate the feed water control valve. This system basically cascades the summer output of the two element system to the feed water flow Controller as a remote set point signal as shown in Figure. This system provides close control during transient condition because the two controllers provide independent tuning to minimize phasing interaction present in the two element approach. The addition of the faster feed water secondary loop assures an immediate correction for feed water disturbances. The drum level controllers accurately compensates for effects of smaller unmeasured flows such as blow down and mismatch between the two flow measurements. As in the two-element system, nearly all the compensation for load changes is handled by the feed forward portion while the drum level feedback loop provides only trimming action. This system can handle large and rapid load changes and feed water disturbances regardless of boiler capacity. This approach is required on multiple boilers having a common feed water supply. It is ideal for plants with both batch and continuous processes where sudden and unpredictable steam demand changes are common.

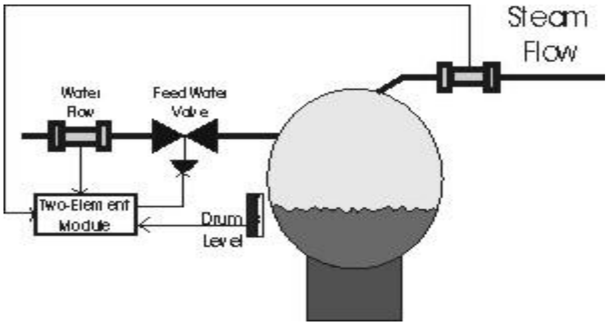


Figure 3.3 Three element control

The three-elements are made up of the following:

Level Element & Steam Flow Element: corrects for unmeasured disturbances within the system such as

- Boiler blow down
- Boiler and superheated tube leaks

Feed water Flow element: responds rapidly to variations in feed water demand, either from the

- Steam flow rate feed forward signal
- Feed water pressure or flow fluctuations

In order to achieve optimum control, both steam and feed water flow values should be corrected for density

Notes:

- The three-element system provides tighter control for drum level with fluctuating steam load. Ideal where a system suffers from fluctuating feed water pressure or flow
- More sophisticated level of control required
- Additional input for feed water flow required

3.3 Enhanced three element drum level control

The enhanced three-element drum level control module incorporates the standard three element level components with the following improvements

- The three-element mode is used during high steam demand. The two-element mode is used if the steam flow measurement fails and the module falls back to single element level control if the feed water flow measurement should fail or if there is a low steam demand.
- The drum level can be derived from up to three independent transmitters and is density compensated for pressure within the boiler drum.

Some points are to be noted

- Tighter control through a choice of control schemes. Drum level maintained on failure of steam or feed water flow measurements.
- This module introduces an additional level control loop

3.4 Drum Level Control Systems:

Steam pressure variations cause density changes in both steam and water in the drum. These density changes affect the differential pressure (DP) between the variable water head in the steam drum and the fixed reference leg which is measured by the level transmitter. Therefore the actual tank level does not agree with the DP head measurement as the pressure in the tank varies due to the steam demand.

In applications with large steam demand fluctuations, the solution to this drum level problem is to use a controller which provides continuous correction or compensation of the measured drum level to correct for variations in steam pressure. This technique is illustrated in the attached drawing.

The drum level is derived from the following equation.

$$h = DP + H(\gamma r - \gamma s) \div (\gamma w - \gamma s) \qquad (2)$$

Where:

h = True drum level – Inches

DP = Measured DP head – Inches

H = Distance between taps – Inches

γs = Steam Specific Gravity (S.G.)

γr = Reference leg (S.G.)

γs = Drum Water (S.G.)

3.5 Drum Level Controller:

This device is usually an indicating two-mode (proportional and integral) controller with high and low alarms regardless of which type system is being considered. Honeywell can supply the dual loop *UDC 3500 Universal Digital Controller* for this function. It also includes, as a standard feature, the feed forward summer function as well as square root extraction for the steam flow differential pressure signal required to liberalize the system. When drum level pressure compensation is required, a UDC 3500 with optional math algorithms can be supplied to provide three-element drum level control plus the level compensation in a single device. Two 8-segment characterizers are used to define the net effect of density changes as a function of steam pressure. These are then used with the math algorithm configured as a “Summer-divider” to calculate the effect of variations in steam pressure on the DP measurement of the liquid interface level in the steam drum. The error caused by the varying steam density is continuously compensated by the math equation, so the calculated process variable used by the level controller PID algorithm is corrected actual level, not the DP head measured by the pressure controller. The level controller output is then used in the same manner as the output in a non-pressure compensated drum level application.

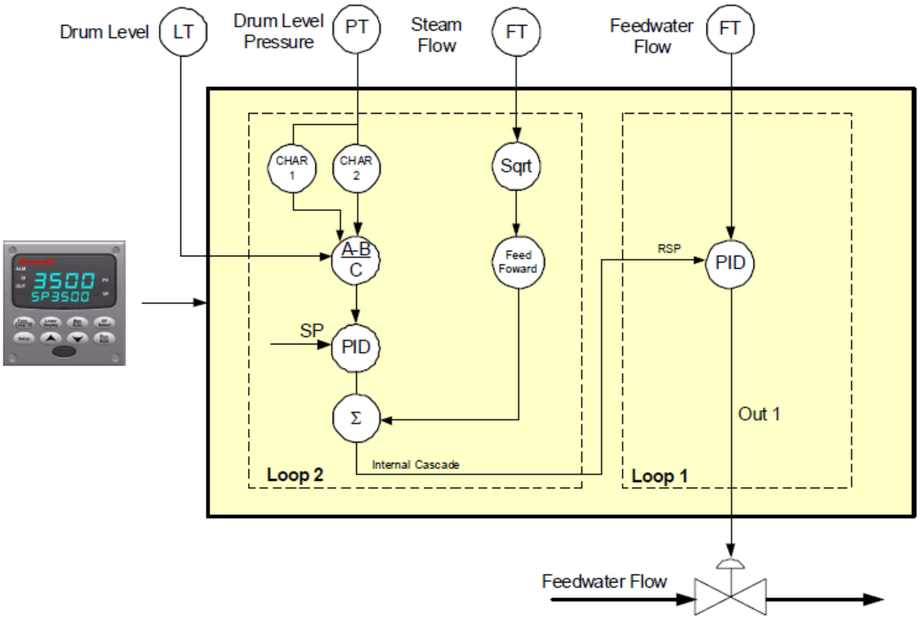


Figure 3.4 Diagram for three element control

3.6 Feed water Flow Controller:

This is loop 1 of the *UDC 3500 Universal Digital Controller*. Loop 1 uses the output of Loop 2 in a cascade configuration as the remote set point. Most feed water flow application only require Proportional and integral to position the feed water control valve. The loop includes square root extraction for the feed water flow transmitter plus auto-manual functionality that allows manual control of the feed water valve. This device is included as part of the dual-loop UDC 3500 that controls the drum level. This dual-loop feature saves cost and panel space while providing a simple operator interface.

CHAPTER 4

METHODOLOGY

4.1 Problem Definition

In the process industries, for the proper functioning of boiler we use to control the three elements as steam out flow, level of fluid, and feed water flow. We can’t control pressure, we can’t control temperature, we can’t control level, the only thing we can control is flow.

A boiler system is an integral component of a thermal power plant, and control of the water level in the drum of the boiler system is a critical operational consideration. For the drum level control, a 3-element proportional-integral-derivative (PID) control is a popular conventional approach. This scheme works satisfactorily in the absence of any process disturbances. However, when there are significant process disturbances, the 3-element PID control scheme does not perform well because of lack of knowledge of proper controller gains to cope with such disturbances. Inevitably over time and use, PID controllers get detuned. Hence, there is good motivation to investigate alternatives to this control scheme. Multivariable control of drum boiler systems has been studied by many researchers.

4.2 Proposed Solution

Multivariable control of drum boiler systems has been studied by many researchers. However, these approaches assume some process model equations (to a more or less extent) to design a controller. It presents a model-free approach in the sense that no plant equations are assumed. The performance of the existing PID control scheme is observed, and collected data is used to gain knowledge about the process. Based on this process knowledge, an intelligent control technique, fuzzy logic control (FLC), is developed. The technique proposed in this was tested on a process simulator. It shows that an intelligent control scheme such as FLC gives better performance in rejecting process disturbances when compared to 3-element PID control scheme.

4.3 Working of the fuzzy controller.

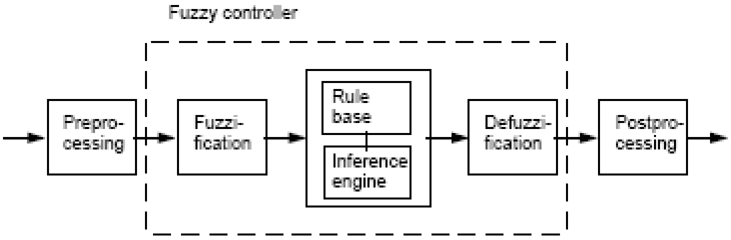


Figure 4.1 Fuzzy controller modal

Above diagram shows how fuzzy controller work with the specified rule base.

One advanced method also here for the better response of system. Model Predictive Control, or MPC, is an advanced method of process control that has been in use in the process industries such as chemical plants and oil refineries. Model predictive controllers rely on dynamic models of the process, most often linear empirical models obtained by system identification. The applied models are determined to depict the behaviour of complex dynamical systems. The models shall compensate for the impact of non-linearities of variables and the chasm caused by non coherent process devolution. Hence the models are used to predict the behaviour of dependent variables (i.e. outputs) of the modelled dynamical system with respect to changes in the process independent variables (i.e. inputs).

Model Predictive Control (MPC) is a multivariable control algorithm that uses:

- an internal dynamic model of the process
- a history of past control moves and
- an optimization cost function J over the receding prediction horizon, to calculate the optimum control moves.

The optimization cost function is given by:

$$J = \sum_{i=1}^{N} w_{x_i}(r_i - x_i)^2 + \sum_{i=1}^{N} w_{u_i}\Delta {u_i}^2 \qquad (3)$$

without violating constraints (low/high limits)

with:

x_i = i -th control variable (e.g. measured temperature)

r_i = i -th reference variable (e.g. required temperature)

u_i = i -th manipulated variable (e.g. control valve)

w_{x_i}= weighting coefficient reflecting the relative importance of x_i

w_{u_i}= weighting coefficient penalizing relative big changes in u_i

4.4 Flow chart for Modal Predictive control.

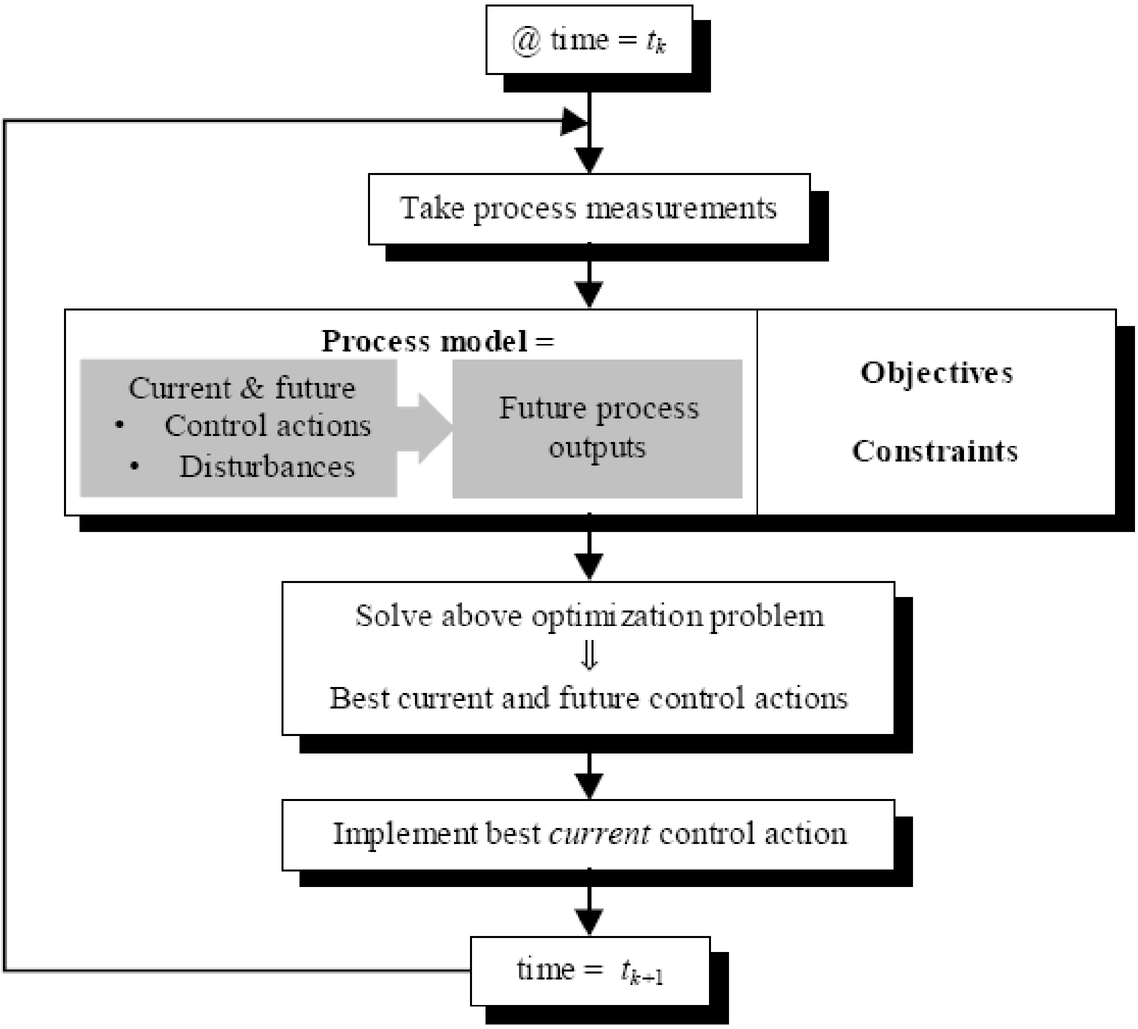


Figure 4.2 Block diagram of MPC

These controllers are used in the controlling of the system to get accurate response. Proposed modal is given here in which controller works as secondary controller.

4.5 Working modal of system

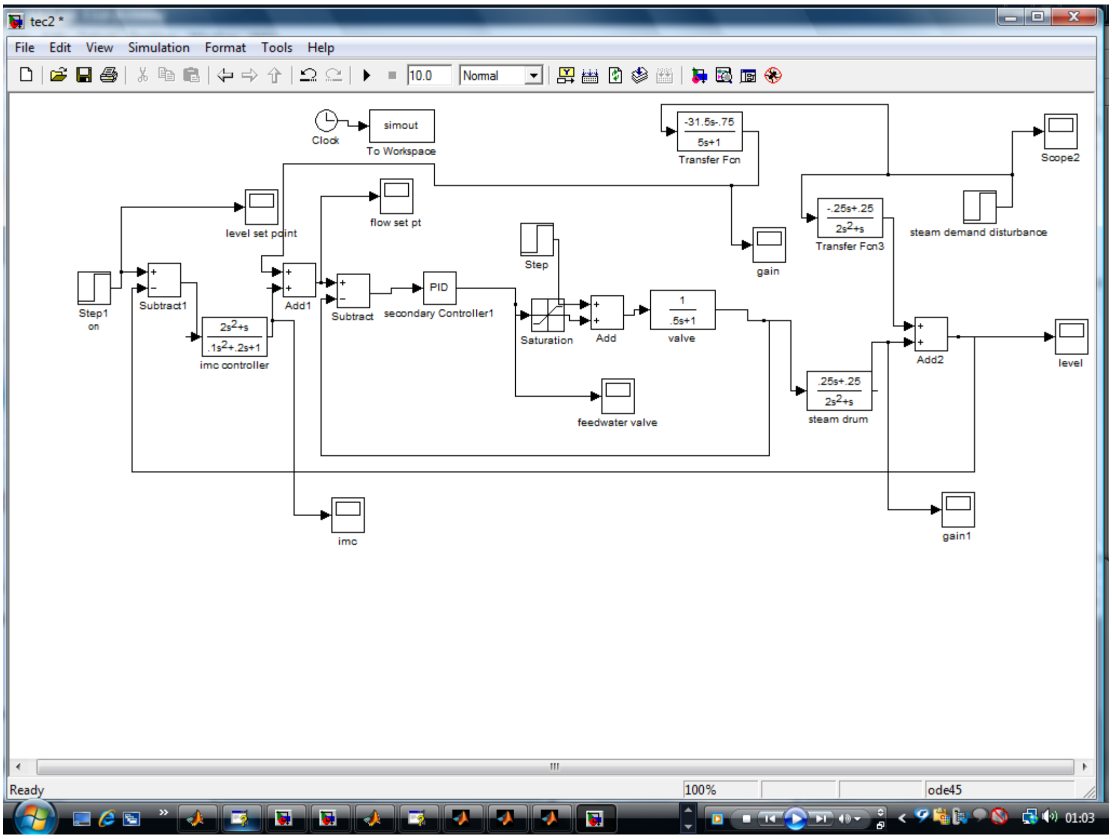


Figure 4.3 Block diagram of system

Above block diagram shows the proposed modal. Only at the place od PID block we will replace first with Fuzzy controller block then with MPC block the analyse the result with two inputs Unit step and Unit ramp.

4.6 Simulink

Simulink (Simulation and Link) is an extension of MATLAB by Mathworks Inc. It works with MATLAB to offer modelling, simulating, and analyzing of dynamical systems under a graphical user interface (GUI) environment. The construction of a model is simplified with click-and-drag mouse operations. Simulink includes a comprehensive block library of toolboxes for both linear and nonlinear analyses. Models are hierarchical, which allow using both top-down and bottom-up approaches. As Simulink is an integral part of MATLAB, it is easy to switch back and forth during the analysis process and thus, the user may take full advantage of features offered in both environments.

4.7 Working with simulink

To start a Simulink session, we need to bring up Matlab program first. From Matlab command window, enter:

>> simulink

Alternately, we may click on the Simulink icon located on the toolbar as shown

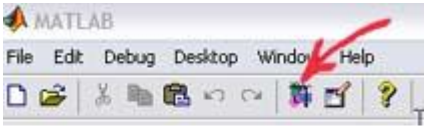


Figure 4.4 Tool bar

Simulink's library browser window like one shown below will pop up presenting the block set for model construction.

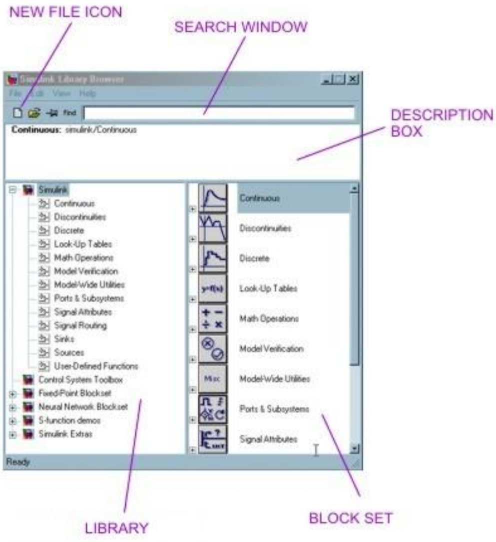


Figure 4.5 Simulink Library Browser

To see the content of the blockset, click on the "+" sign at the beginning of each toolbox.

To start a model click on the NEW FILE ICON as shown in the screen shot above. Alternately, we may use keystrokes **CTRL+N**.

A new window will appear on the screen. You will be constructing your model in this window. Also in this window the constructed model is simulated. A screenshot of a typical working (model) window is shown below:

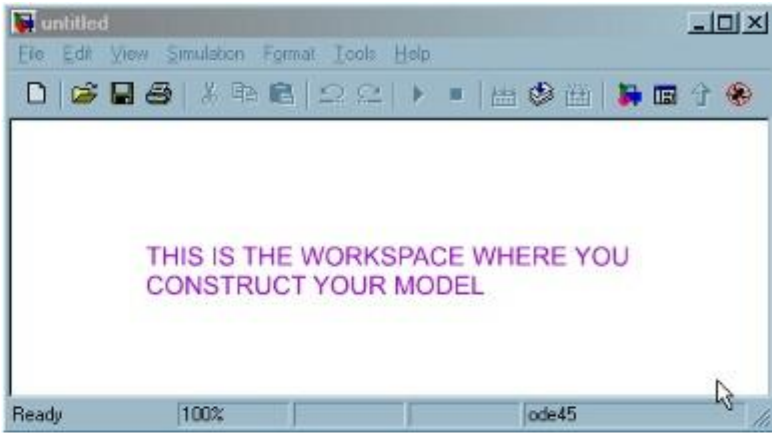


Figure 4.6 Workspace window

To become familiarized with the structure and the environment of Simulink, we are encouraged to explore the toolboxes and scan their contents. We may not know what they are all about at first, but perhaps we could catch on the organisation of these toolboxes according to their categories. For instance, we may see that the Control System toolbox consists of the Linear Time Invariant (LTI) system library and the MATLAB functions can be found under Function and Tables of the Simulink main toolbox. A good way to learn Simulink (or any computer program in general) is to practice and explore. Making mistakes is part of the learning curve. A simple model is used here to introduce some basic features of Simulink. Please follow the steps below to construct a simple model.

STEP 1: CREATING BLOCKS.

From BLOCK SET CATEGORIES section of the SIMULINK LIBRARY BROWSER window, click on the "+" sign next to the **Simulink** group to expand the tree and select (click on) **Sources**.

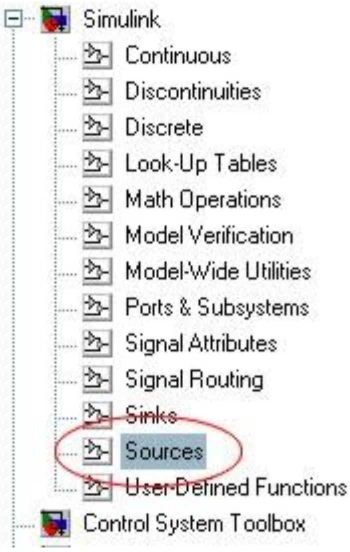
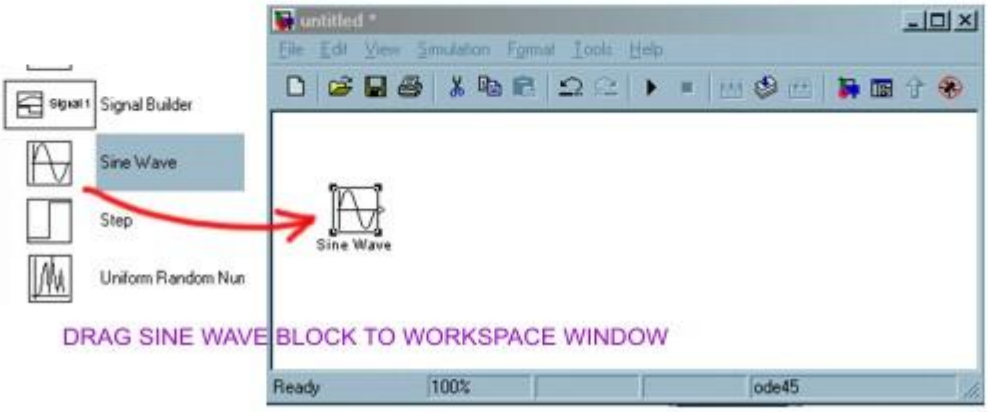


Figure 4.7 List of Blocks

A set of blocks will appear in the BLOCKSET group. Click on the **Sine Wave** block and drag it to the workspace window (also known as model window).



DRAG SINE WAVE BLOCK TO WORKSPACE WINDOW

Figure 4.8 Dragging of block on window

.

NOTE It is advisable that we save your model at some point early on so that if our PC crashes we wouldn't loose too much time reconstructing our model.

Now save this model under the filename: "simexample1". To save a model, we may click on the floppy diskette icon 🖫. or from FILE menu, select **Save** or using keystrokes CTRL+S. All Simulink model file will have an extension "**.mdl**". Simulink recognises file with *.mdl* extension as a simulation model (similar to how MATLAB recognises files with the extension .m as an MFile). Continue to build model by adding more components (or blocks) to model window. We'll continue to add a **Scope** from **Sinks** library, an **Integrator** block from **Continuous** library, and a **Mux** block from **Signal Routing** library.

To move the blocks around, simply click on it and drag it to a desired location.

Once you've dragged over all necessary blocks, the workspace window should consist of the following components:

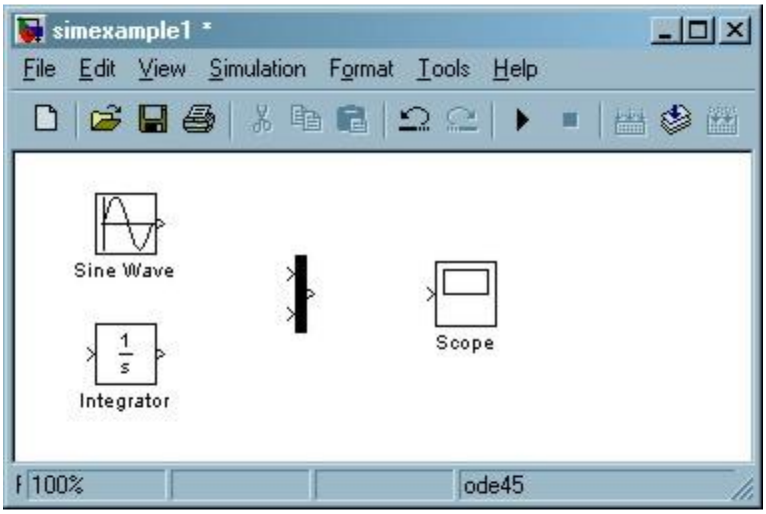


Figure 4.9 Example taken

You may remove (delete) a block by simply clicking on it once to turn on the "select mode" (with four corner boxes) and use the DEL key or keys combination CTRL-X.

STEP 2: MAKING CONNECTIONS

To establish connections between the blocks, move the cursor to the output port represented by ">" sign on the block. Once placed at a port, the cursor will turn into a cross "+" enabling you to make connection between blocks.

To make a connection: left-click while holding down the control key (on your keyboard) and drag from source port to a destination port.

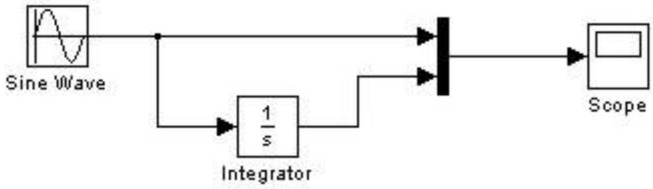


Figure 4.10 Connection of blocks

A sine signal is generated by the Sine Wave block (a source) and is displayed by the scope. The integrated sine signal is sent to scope for display along with the original signal from the source via the **Mux**, whose function is to multiplex signals in form of scalar, vector, or matrix into a bus.

STEP 3: RUNNING SIMULATION

You now may run the simulation of the simple system above by clicking on the play button ▶. Alternately, you may use keystrokes CTRL+T, or choose Start submenu (under Simulation menu).

Double click on the Scope block to display of the scope.

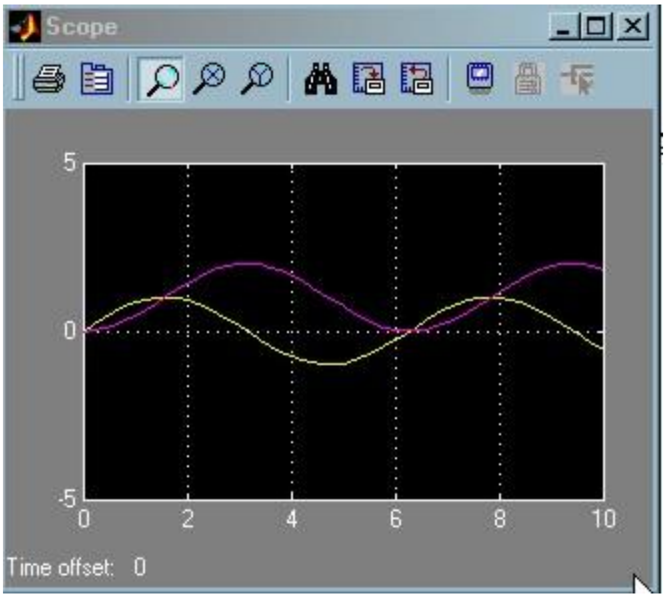


Figure 4.11 Scope

It shows the simulation graph on the scope from this we can analyse the performance of system.

CHAPTER 5

SIMULATION AND TESTING

5.1 Introduction

A boiler system is an integral component of a thermal power plant, and control of the water level in the drum of the boiler system is a critical operational consideration. For the drum level control, a 3-element proportional-integral-derivative (PID) control is a popular conventional approach. This scheme works satisfactorily in the absence of any process disturbances. However, when there are significant process disturbances, the 3-element PID control scheme does not perform well because of lack of knowledge of proper controller gains to cope with such disturbances. Inevitably over time and use, PID controllers get detuned. Hence, there is good motivation to investigate alternatives to this control scheme. Multivariable control of drum boiler systems has been studied by many researchers. However, these approaches assume some process model equations (to a more or less extent) to design a controller. It presents a model-free approach in the sense that no plant equations are assumed. The performance of the existing PID control scheme is observed, and collected data is used to gain knowledge about the process. Based on this process knowledge, an intelligent control technique, fuzzy logic control (FLC), is developed. The technique proposed in this was tested on a process simulator. It shows that an intelligent control scheme such as FLC gives better performance in rejecting process disturbances when compared to 3-element PID control scheme.

In thermal power plants, there are several process variables which are critical to proper operation of the process of the power generation. Multivariable control of power plants has been studied by many researchers. An analysis and comparison of different low-order boiler models have been carried out. Such models can be useful in power system dynamics studies. In [2], data and control schemes for small and medium size boiler models are presented. In particular, when controllers utilize simplified boiler models as a part of their control law, such models are useful. An optimal control of a drum boiler power plant is described in [3], which uses a plant model after estimating different parameters. Initially, a ninth order nonlinear lumped parameter model is linearized at different operating points and a number of parameters are estimated by an identification procedure using a complete set of plant trials. A model reduction is then performed to get a simplified control structure. The application of a predictive adaptive control system to the control and optimization of the process in a coal power plant station has been presented in [4]. This method is a variation of model reference adaptive control in which the predictive model is modified by an adaptive mechanism to achieve the desired objective. Some methods as an alternative to the standard PI control have been suggested to control the steam pressure and steam temperature in the boiler system. An application of generalized predictive control to achieve a self-tuning control of superheat steam pressure of a 200 MW drum boiler has appeared in [5].In [6], adaptive optimal control of steam temperature for thermal power plants has been studied, it proposes a process model which is represented by a multi-input and output autoregressive moving average model. The model parameters are identified on-line during low load and high load level of power plant operation. The optimal control gains are calculated using the model by the dynamic programming method. Recently there have been many developments in the area of artificial intelligence (AI) techniques applied to control problems.

Artificial neural networks, fuzzy logic systems (FLSs), expert systems and genetic algorithms are some of the tools of AI which are being investigated for their suitability to certain control Authorized licensed problems [7]. These control problems are either intractable or not well handled by conventional techniques. It exploits the FLS to control the drum level in a boiler system. Fuzzy logic was first advocated by Professor L. A. Zadeh in 1965. The concept of fuzzy system modeling by combining mathematical modeling with the linguistic descriptions used in expert systems was also introduced by Zadeh [8]. Control of cement kilns, electric trains, water purification plants and other facilities have actually been carried out using fuzzy logic [9]. Fuzzy logic represents one of the model-free approaches to the problems of system identification and control.

5.2 PID control scheme

This scheme in conventional method to control the system It is combination of three controller given below.

5.2.1 PID Controller

A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly and rapidly, to keep the error minimal.

The PID controller calculation (algorithm) involves three separate parameters; the proportional, the integral and derivative values. The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element. By tuning the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability.

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 outputs to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. 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.

Note: Due to the diversity of the field of control theory and application, many naming conventions for the relevant variables are in common use.

5.2.2 PID controller theory

This section describes the parallel or non-interacting form of the PID controller. For other forms please see the Section "Alternative notation and PID forms".

The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). Hence:

$$\mathrm{MV(t)} = P_{\mathrm{out}} + I_{\mathrm{out}} + D_{\mathrm{out}} \tag{4}$$

where:

P_{out}, I_{out}, and D_{out} are the contributions to the output from the PID controller from each of the three terms, as defined below

5.2.3 Proportional term

The proportional term (sometimes called *gain*) makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain.

The proportional term is given by:

$$P_{\mathrm{out}} = K_p\, e(t) \tag{5}$$

where

P_{out}: Proportional term of output

K_p: Proportional gain, a tuning parameter

e: Error = $SP - PV$

t: Time or instantaneous time (the present)

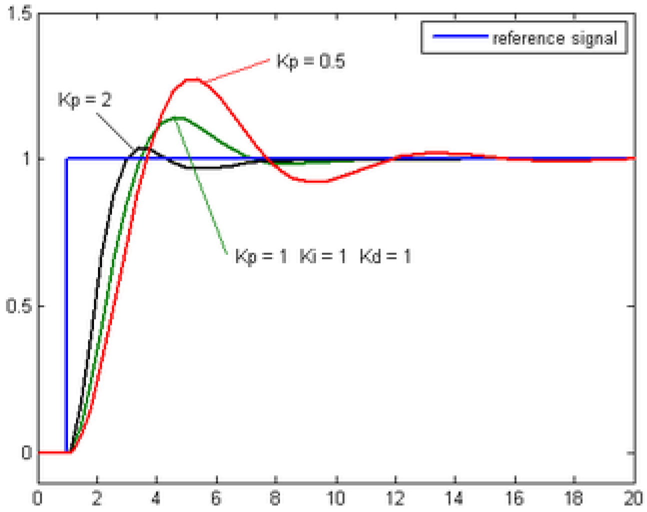


Figure 5.1 Plot of PV vs time, for three values of K_p (K_i and K_d held constant)

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable (See the section on loop tuning). In contrast, a small gain results in a small output response to a large input error, and a less responsive (or sensitive) controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances.

In the absence of disturbances, pure proportional control will not settle at its target value, but will retain a steady state error that is a function of the proportional gain and the process gain. Despite the steady-state offset, both tuning theory and industrial practice indicate that it is the proportional term that should contribute the bulk of the output change.

5.2.4 Integral term

The contribution from the integral term (sometimes called *reset*) is proportional to both the magnitude of the error and the duration of the error. Summing the instantaneous error over time (integrating the error) gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain and added to the controller output. The magnitude of the contribution of the integral term to the overall control action is determined by the integral gain, K_i. The integral term is given by:

$$I_{\text{out}} = K_i \int_0^t e(\tau)\, d\tau \qquad (6)$$

where

I_{out}: Integral term of output

K_i: Integral gain, a tuning parameter

e: Error = $SP - PV$

t: Time or instantaneous time (the present)

τ: a dummy integration variable

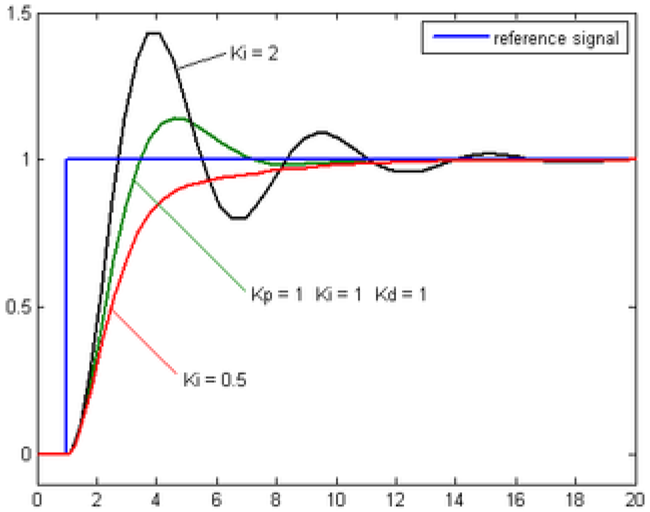


Figure 5.2 Plot of PV vs time, for three values of K_i (K_p and K_d held constant)

The integral term (when added to the proportional term) accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a proportional only controller. However, since the integral term is responding to accumulated errors from the past, it can cause the present value to overshoot the set point value (cross over the set point and then create a deviation in the other direction). For further notes regarding integral gain tuning and controller stability, see the section on loop tuning. The rate of change of the process error is calculated by determining the slope of the error over time (i.e., its first derivative with respect to time) and multiplying this rate of change by the derivative gain K_d. The magnitude of the contribution of the derivative term (sometimes called *rate*) to the overall control action is termed the derivative gain, K_d.

The derivative term is given by:

$$D_{\text{out}} = K_d \frac{de}{dt}(t) \qquad (7)$$

where

D_{out}: Derivative term of output

K_d: Derivative gain, a tuning parameter

e: Error = $SP - PV$

t: Time or instantaneous time (the present)

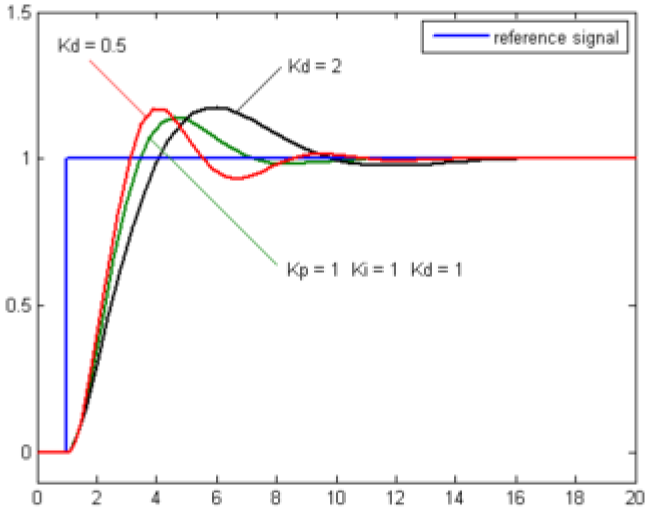


Figure 5.3 Plot of PV vs time, for three values of K_d (K_p and K_i held constant)

The derivative term slows the rate of change of the controller output and this effect is most noticeable close to the controller set point. Hence, derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability. However, differentiation of a signal amplifies noise and thus this term in the controller is highly sensitive to noise in the error term, and can cause a process to become unstable if the noise and the derivative gain are sufficiently large.

The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining *u*(*t*) as the controller output, the final form of the PID algorithm is:

$$\mathrm{u(t)} = \mathrm{MV(t)} = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de}{dt}(t) \tag{8}$$

where the tuning parameters are:

Proportional gain, K_p

Larger values typically mean faster response since the larger the error, the larger the Proportional term compensation. An excessively large proportional gain will lead to process instability and oscillation.

Integral gain, K_i

Larger values imply steady state errors are eliminated more quickly. The trade-off is larger overshoot: any negative error integrated during transient response must be integrated away by positive error before we reach steady state.

Derivative gain, K_d

Larger values decrease overshoot, but slows down transient response and may lead to instability due to signal noise amplification in the differentiation of the error.
Block diagram in the simulink used as:

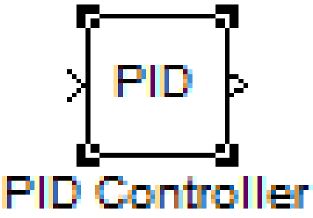
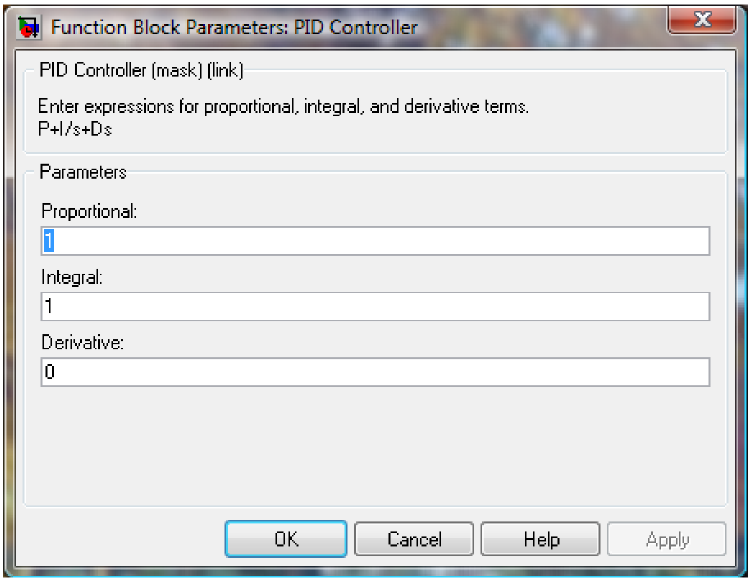


Figure 5.4 Block diagram of PID controller

This block implements a PID controller where parameters are entered for the Proportional, Integral and Derivative terms. Unmask this block to see how it works. The derivative term is implemented using a true derivative block


Function Block Parameters: PID Controller

PID Controller (mask) (link)

Enter expressions for proportional, integral, and derivative terms.
P+I/s+Ds

Parameters

Proportional: 1

Integral: 1

Derivative: 0

Figure 5.5 Block parameters

In this section we will use PID controller for the drum level control and the standard 3-element control. When there are no process disturbances (such as SP change or load change), a conventional 3-element PID scheme works nicely and drum level is maintained around SP. Hence, the proposed control scheme utilizes the existing 3-element PID scheme in the absence of any disturbances and an FLC when there are process disturbances. The observer keeps track of different variables such as measured feed water flow (MFWF), measured steam flow (MSF), MDL, SP, SF DMD and HA station demand (controller output or %valve opening (% VO)). The proposed scheme utilizes process knowledge and performance of existing PID control scheme. The main idea is that for preserving MDL at a given SP, MFWF should balance MSF. When a SP is increased or decreased, MFWF should be increased or decreased temporarily and then it should be brought in balance with MSF. Thus, MSF is used to provide a base controller output u_i which is determined from a mapping between MFWF and % VO. The mapping between MFWF and %VO can be obtained by observing the controller output and corresponding MFWF when the 3-element PID schemes operating. The difference between MDL and SP is used to provide an incremental controller output u_i, so as to increase or decrease the MDL to the desired SP. shows a simplified block diagram of a power generation process in a thermal power plant.

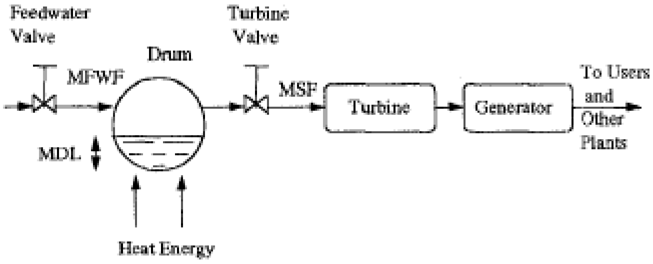


Figure 5.6 Block diagram for power generation process

Feed water enters the drum through a feed water valve. The heat energy converts water in the drum into steam. The steam drives the turbine and the generator coupled to the turbine produces electricity. One of the important considerations is to keep the level of water in the drum1 at a desired set point. The standard 3-elernent PID control works well under steady-state conditions, however, there are two types of disturbances, affecting the equilibrium in the drum: set point (SP) change and steam flow demand (SF DMD) change (or load change). Occasionally, the set point is changed. Also, SF DMD is changed depending upon the electricity demand to be met. When there is a load change, the % element PID control being detuned may not give satisfactory performance because of the phenomena known as shrink and swell. Moreover, the feel water valve can assume different characteristics such as linear, nonlinear and sticky. The objective is to keep the measured drum level (MDL) is close to SP as possible in spite of disturbances. An intelligent control scheme cans mitigate the effect of process disturbances on MDL. Fig.5.2 shows the basic block diagram of a 3-element PID control scheme.

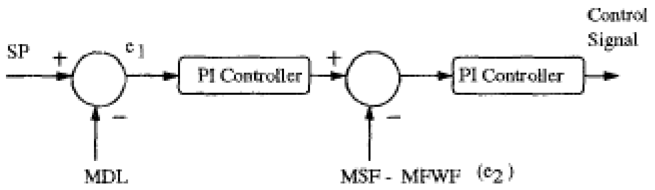


Figure 5.7 3-Element PID control

The three elements involved are drum level, steam flow and feed water flow. Drum level is compared with set point and the resulting error e_1,is acted upon by proportional action and integral action. The resulting (output is summed with the steam flow signal to create a feed water flow demand. Feed water flow demand is compared with feed water flow and the resulting error is acted upon by proportional action and integral action. The resulting output provides the control signal to the feed water valve. The difference between the MSF and the MW'F is referred to as e_2 .

Block diagram of simulink model using PID controller is shown as under

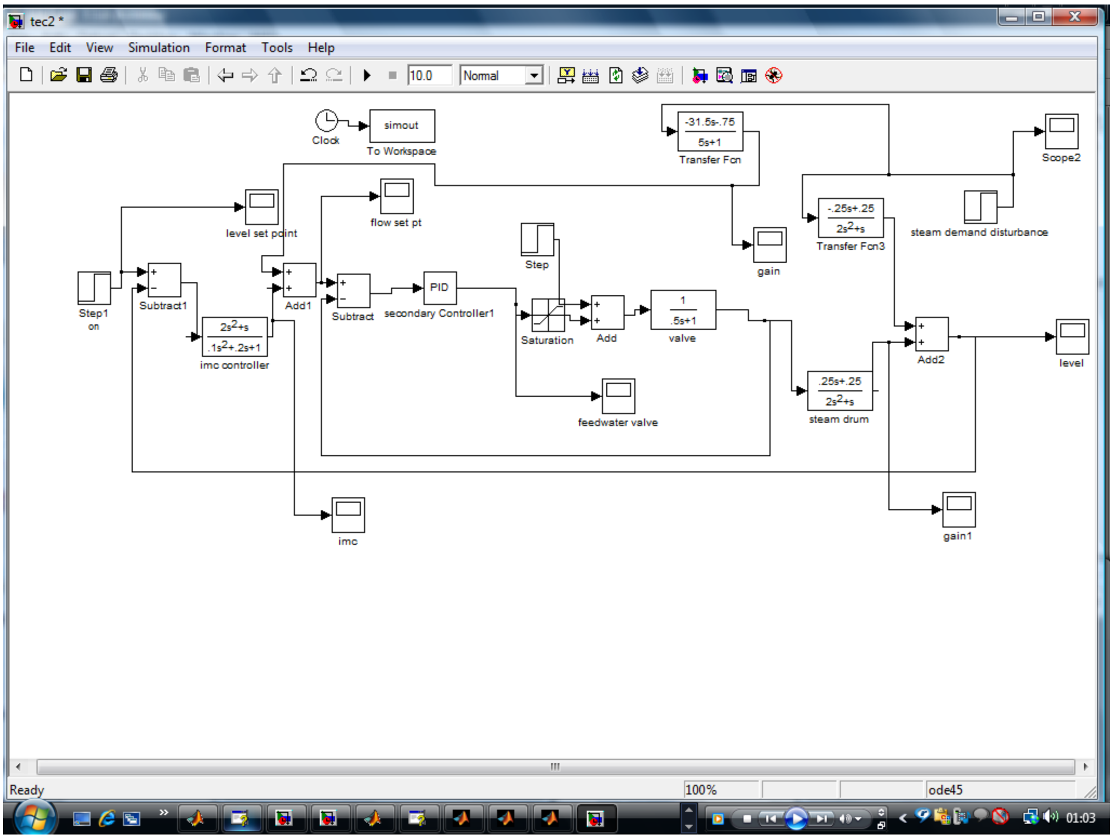


Figure 5.8 Fig block diagram using PID controller

In the above modal PID controller work as secondary controller and IMC controller work as primary controller. This is particularly true when the secondary control loops involves flow control as shown here. At the set point step input is taken, we can also have different response with different input such as ramp input parabolic input. Response of the above said block is given in the 6 chapter.

5.3 Fuzzy Logic System

Fuzzy logic systems have been praived to be universal approximators and hence these are good candidates for solving complex control problems. Some of the advantages of fuzzy logic are that they are nonlinear, adaptive, can admit a high degree of parallel implementation, and can tolerate uncertainty in the system. More importantly, certain aspects of the skill of process operators can be incorporated into the design of an FLS. Such information can furtlier be refined based on the performance of the system. FLC will be used to denote fuzzy logic control or fuzzy logic controller. An FLC is easy to design if sufficient process knowledge is available.

5.4 An Intelligent control scheme using FLS

This section presents an intelligent control scheme using FLS. A brief introduction to the relevant aspects of the FLS is given, and the application of the FLS to the problem under consideration is illustrated. Proposed Intelligent Control Scheme scheme is given in Fig.5.3.The detailed illustration of the proposed control is given as under.

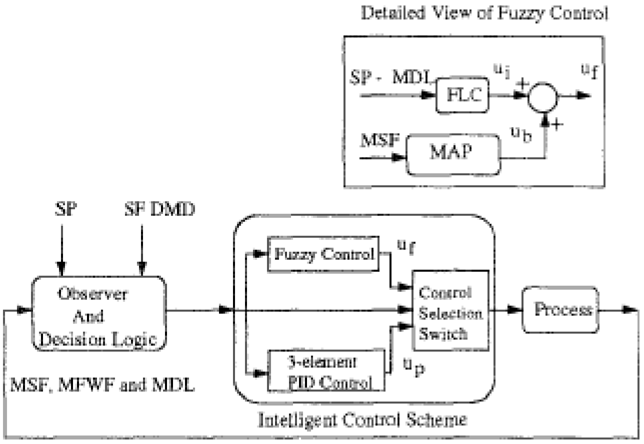


Figure 5.9 Control using FLS

The proposed intelligent control scheme has several advantages over the standard control scheme. The proposed techniques use error-based tuning (adjustment of FLC parameters), and the same nature of response is obtained regardless of the magnitude of SP or SF DMD changes. On the other hand, the standard control scheme gives different kinds of responses for different magnitudes of SP/SF DMD changes. For example, the standard control scheme would give a large overshoot for an SP change of 4units and less overshoot for an SP change of 2 units. Also, the process characteristics are different at low load and high load and the PID controllers tuned at one operating point would not work with the same effectiveness at some other operating point. However, the proposed techniques are self-tuning, and would work with the same effectiveness regardless of the operating point.

5.5 Fuzzy Logic Control (FLC) Technique

A fuzzy logic system (FLS) is the building block in most systems incorporating fuzzy logic. An FLC can be implemented in the form of an FLS. One form of an FLC consists of a fuzzifier, a rule base, an inference engine and a defuzzifier.

5.5.1 Fuzzifier

The fuzzifier is the plant-to-fuzzy logic system interface and performs a mapping from real-valued variables into fuzzy variables. A Gaussian function is used to determine the degree of membership of crisp points to fuzzy sets in the antecedent parts of the fuzzy logic rules.

5.5.2 Fuzzy rule base

The fuzzy rule base consists of a collection of fuzzy rules. Fuzzy rules can be developed by two different methods. One method is to derive IF-THEN rules based on the knowledge. Another method is to select a few data as input-output pairs to determine IF-THEN rules. When fuzzy logic rules are obtained from input/output data, data pairs can become the canters of appropriate fuzzy regions, which correspond to appropriate fuzzy variables. Either of these two methods alone is ineffective as explained next.

5.5.3 Process knowledge and FL rules

When SP is the same as MDL and SF DMD is *SO%*, VO is *50%* for a linear valve. Consider the case of a SP change from 20 to 24. If only the knowledge of the system is used, it would mean that the feed water valve should be opened to a comparatively large extent (e.g. 60%) when there is a large e_1 As MDL approaches SP, the feed water valve should be opened to a comparatively smaller and smaller extent (e.g. 55%) until SP equals MDL, in which case VO should be 50%. However, this method necessitates that different %VO be tried in order to arrive at proper % VO for different e_1's. Otherwise this method might give large overshoot and undershoot of drum level.

5.5.4 Numerical data and FLC rules

If the performance of the PID controller for an SP change is observed, it is found that the MDL reaches SP gradually; however, comparatively more % VO is provided for lower magnitude error and comparatively less % VO is provided for higher magnitude. Since only e_1 is intended to be used in deriving the fuzzy logic rules here, it is illogical to imitate the PID actions directly in this way.

5.5.6 Fuzzy inference engine

In the fuzzy inference engine, fuzzy logic principles are used to combine the fuzzy IF-THEN rules in the fuzzy rule base into a certain mapping. The product operation rule is used in the fuzzy inference engine.

5.5.7 Defuzzifier

The defuzzifier is the fuzzy logic system-to-plant (or building) interface and performs a mapping from fuzzy variables to real-valued variables. The center average defuzzifier is used. The variables for a single input (x) and a single output. For the simulation of boiler using fuzzy controller, we will take input as level of the boiler and flow of the steam and opening and closing of valve to control feed water flow as output.

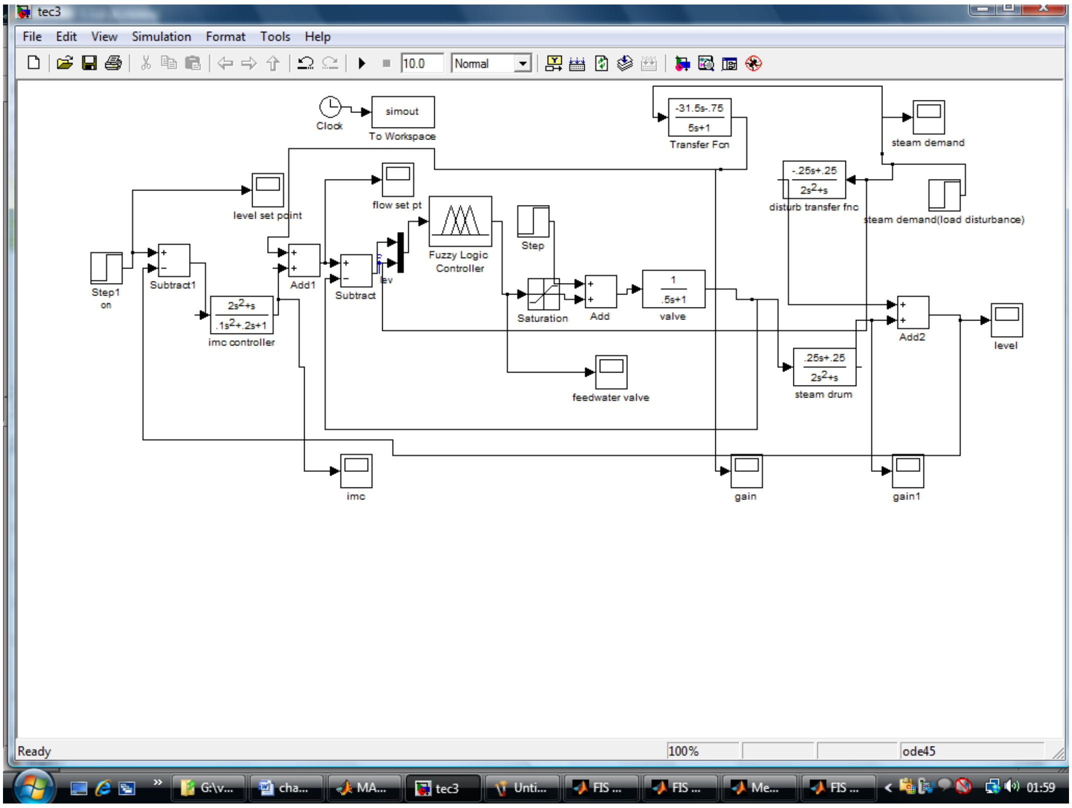
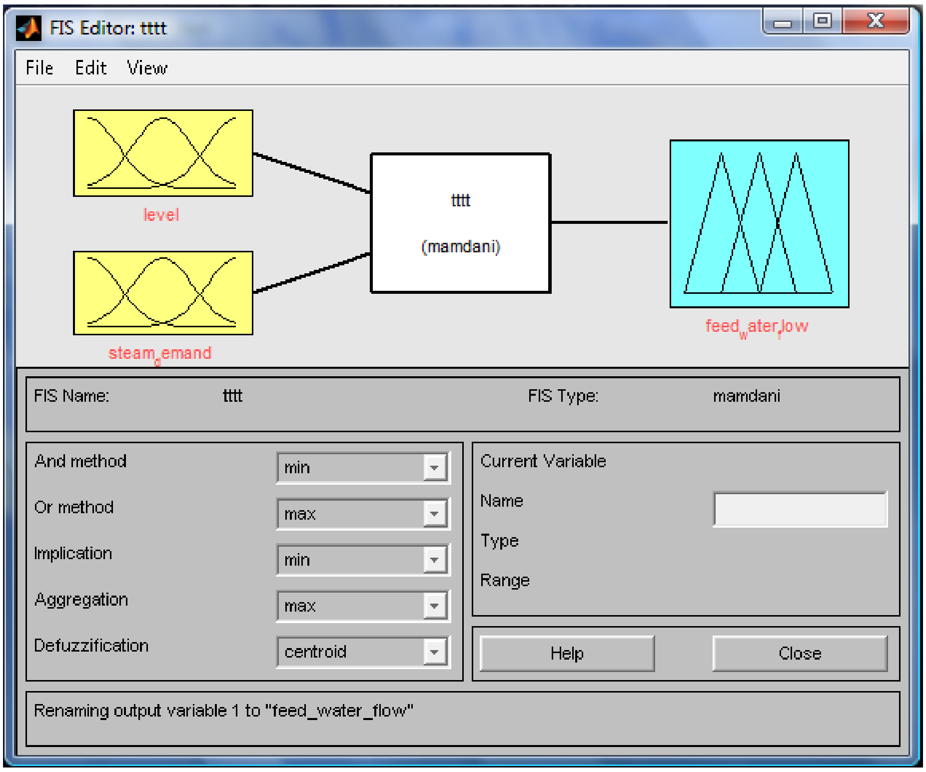


Figure 5.10 Fig Block diagram using Fuzzy controller

In the above modal Fuzzy controller work as secondary controller and IMC controller work as primary controller. Different rules will fire and we will get the response.



FIS Name: tttt

FIS Type: mamdani

And method: min

Or method: max

Implication: min

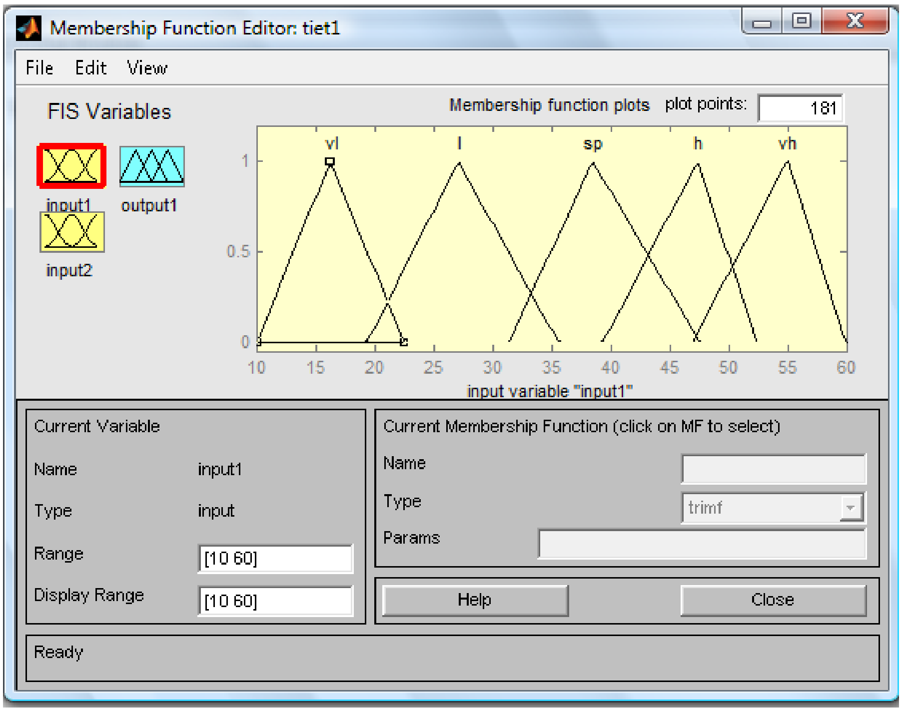
Aggregation: max

Defuzzification: centroid

Renaming output variable 1 to "feed_water_flow"

Figure 5.11 Fuzzy Logic Toolbox (Using mamdani method)

Above block shows the FIS system, in which we have taken two inputs as drum level and steam demand which give disturbance to the system. Now we will take the range of both input and output.



plot points: 181

Current Variable

Name: input1

Type: input

Range: [10 60]

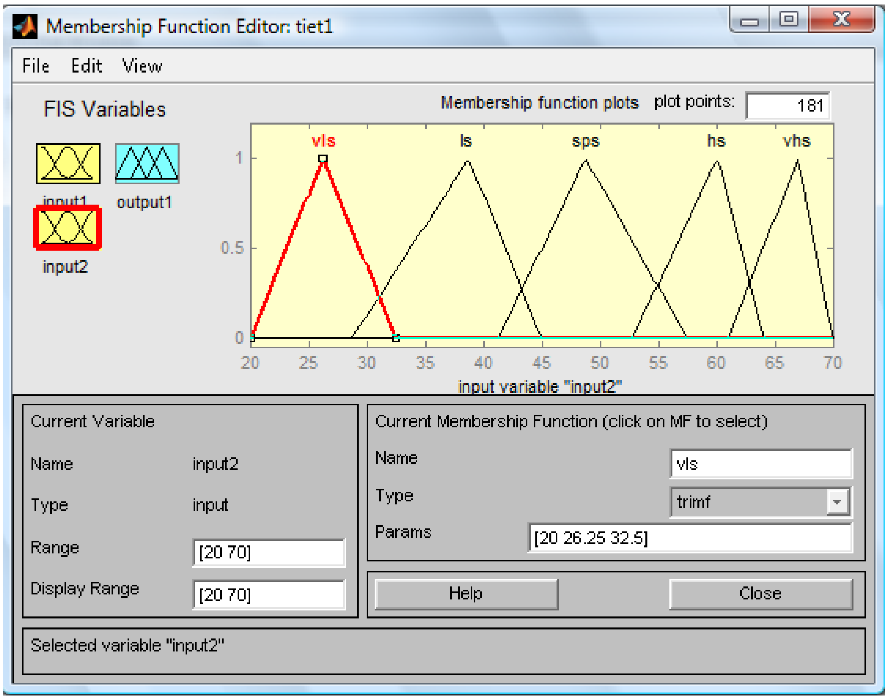
Display Range: [10 60]

Type: trimf

Ready

Figure 5.12 Input1 Membership Function

It shows the membership function plots for the input variable level. It has members as vl(very low),l(low),h(high),vh(very high).Specify the range then assign the variable name. Now the second input is steam demand. Again member ship functions are assigned with range. Range is taken from 10 to 60



plot points: 181

Current Variable

Name: input2

Type: input

Range: [20 70]

Display Range: [20 70]

Current Membership Function (click on MF to select)

Name: vls

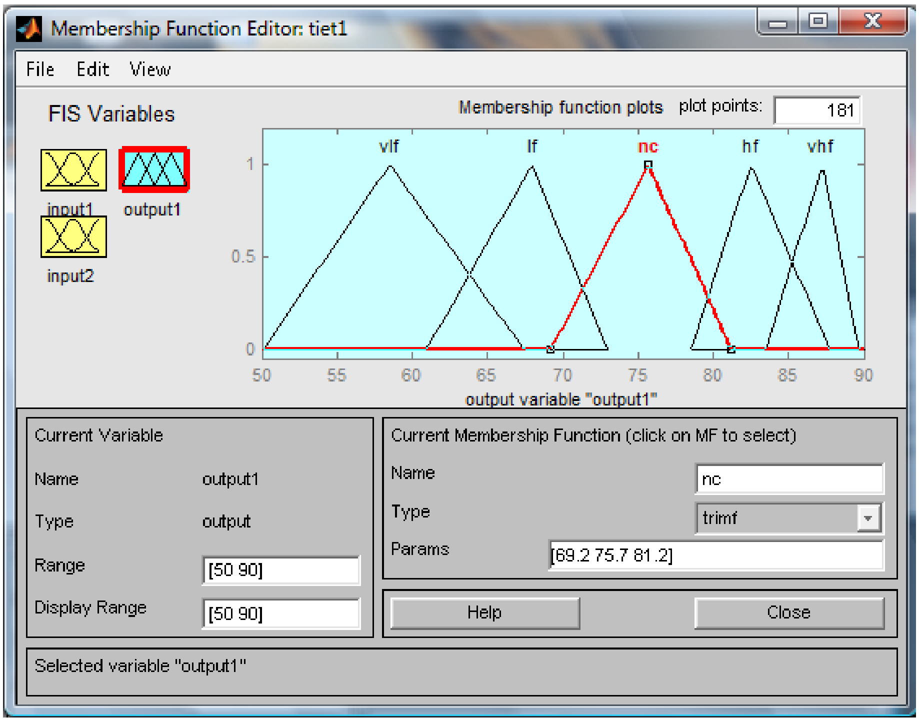
Type: trimf

Params: [20 26.25 32.5]

Selected variable "input2"

Figure 5.13 Input2 member ship function

The variables are vls(very low steam),ls(low steam),sps(set point steam),hs(high steam),vhs(very high steam)



plot points: 181

Current Variable

Name: output1

Type: output

Range: [50 90]

Display Range: [50 90]

Current Membership Function (click on MF to select)

Name: nc

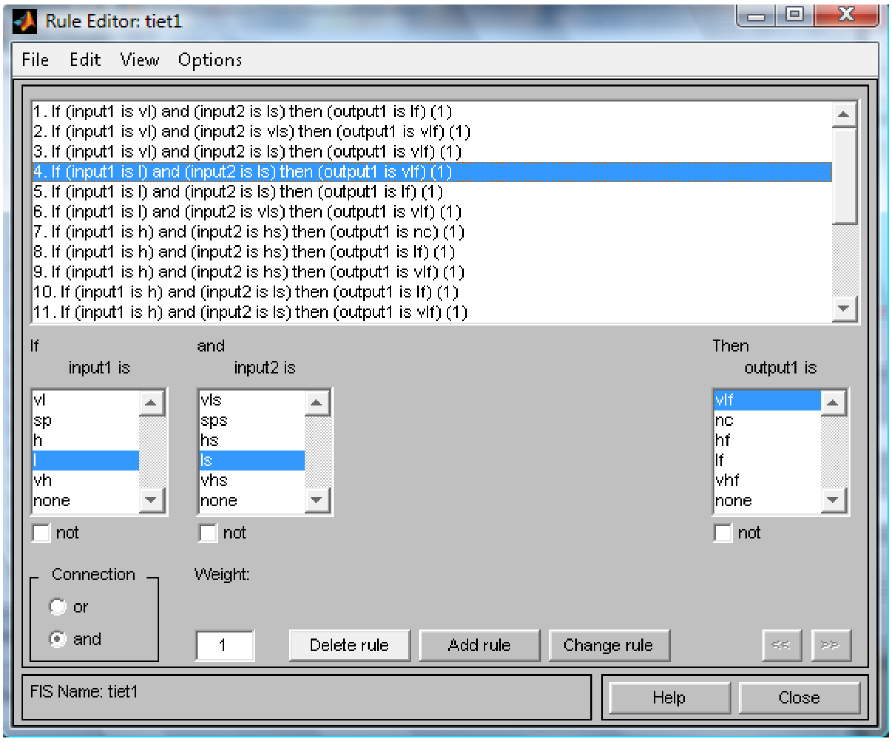
Type: trimf

Params: [69.2 75.7 81.2]

Selected variable "output1"

Figure 5.14 Output Membership Function

It shows the rule based of the fuzzy logic controller for the three element control system. Consist of nineteen rule based using If-and-then rules condition. Example one of the rules “If Input1 is vl and Input2 is ls then outpu1 is lf.



```
1. If (input1 is vl) and (input2 is ls) then (output1 is lf) (1)
2. If (input1 is vl) and (input2 is vls) then (output1 is vlf) (1)
3. If (input1 is vl) and (input2 is ls) then (output1 is vlf) (1)
4. If (input1 is l) and (input2 is ls) then (output1 is vlf) (1)
5. If (input1 is l) and (input2 is ls) then (output1 is lf) (1)
6. If (input1 is l) and (input2 is vls) then (output1 is vlf) (1)
7. If (input1 is h) and (input2 is hs) then (output1 is nc) (1)
8. If (input1 is h) and (input2 is hs) then (output1 is lf) (1)
9. If (input1 is h) and (input2 is hs) then (output1 is vlf) (1)
10. If (input1 is h) and (input2 is ls) then (output1 is lf) (1)
11. If (input1 is h) and (input2 is ls) then (output1 is vlf) (1)
```

Figure 5.15 Rule base

Above window shows the various rules for the controller. Then the FIS is saved in the workspace and then embed into the controller. Simulation and block diagram of system to be controlled is given in next chapter.

5.6 MPC controller (Modal predictive Controller)

Model Predictive Control, or MPC, is an advanced method of process control that has been in use in the process industries such as chemical plants and oil refineries since the 1980s. Model predictive controllers rely on dynamic models of the process, most often linear empirical models obtained by system identification.

The applied models are determined to depict the behaviour of complex dynamical systems. The models shall compensate for the impact of non-linearities of variables and the chasm caused by non coherent process devolution.

Hence the models are used to predict the behaviour of dependent variables (i.e. outputs) of the modelled dynamical system with respect to changes in the process independent variables (i.e. inputs). In chemical processes, independent variables are most often set points of regulatory controllers that govern valve movement (e.g. valve positioners with or without flow, temperature or pressure controller cascades), while dependent variables are most often constraints in the process (e.g. product purity, equipment safe operating limits). The model predictive controller uses the models and current plant measurements to calculate future moves in the independent variables that will result in operation that honours all independent and dependent variable constraints. The MPC then sends this set of independent variable moves to the corresponding regulatory controller set points to be implemented in the process.

Despite the fact that most real processes are approximately linear within only a limited operating window, linear MPC approaches are used in the majority of applications with the feedback mechanism of the MPC compensating for prediction errors due to structural mismatch between the model and the process. In model predictive controllers that consist only of linear models, the superposition principle of linear algebra enables the effect of changes in multiple independent variables to be added together to predict the response of the dependent variables. This simplifies the control problem to a series of direct matrix algebra calculations that are fast and robust

5.6.1 Theory behind MPC

MPC is based on iterative, finite horizon optimization of a plant model. At time t the current plant state is sampled and a cost minimizing control strategy is computed (via a numerical minimization algorithm) for a relatively short time horizon in the future: $[t, t + T]$. Specifically, an online or on-the-fly calculation is used to explore state trajectories that emanate from the current state and find (via the solution of Euler-Lagrange equations) a cost-minimizing control strategy until time $t + T$. Only the first step of the control strategy is implemented, then the plant state is sampled again and the calculations are repeated starting from the now current state, yielding a new control and new predicted state path. The prediction horizon keeps being shifted forward and for this reason MPC is also called receding horizon control. Although this approach is not optimal, in practice it has given very good results

5.6.2 Principles of MPC

Model Predictive Control (MPC) is a multivariable control algorithm that uses:

- an internal dynamic model of the process
- a history of past control moves and
- an optimization cost function J over the receding prediction horizon,

to calculate the optimum control moves.

The optimization cost function is given by:

$$J = \sum_{i=1}^{N} w_{x_i}(r_i - x_i)^2 + \sum_{i=1}^{N} w_{u_i}\Delta u_i^{\,2} \qquad (9)$$

without violating constraints (low/high limits)

with:

x_i = i -th control variable (e.g. measured temperature)

r_i = i -th reference variable (e.g. required temperature)

u_i = i -th manipulated variable (e.g. control valve)

w_{x_i}= weighting coefficient reflecting the relative importance of x_i

w_{u_i}= weighting coefficient penalizing relative big changes in u_i

etc.

Below block diagram shows the basic scheme for Modal Predictive control.

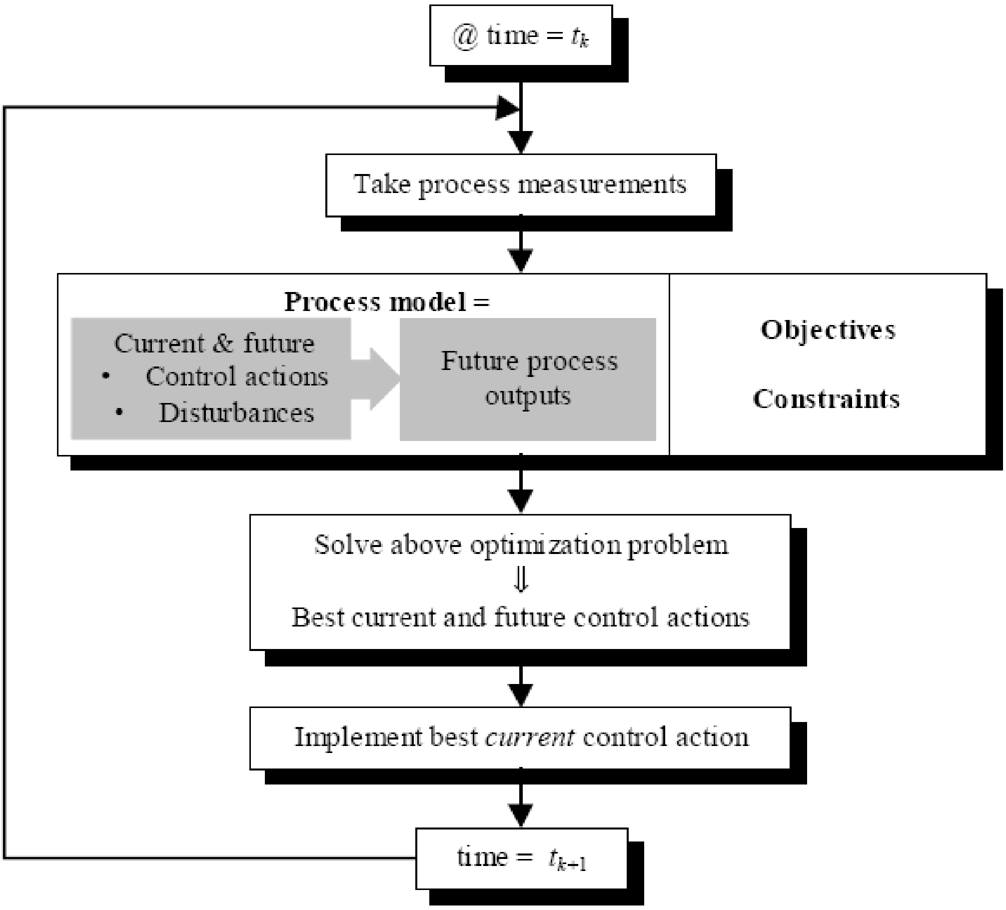


Figure 5.16 Scheme for Modal Predictive control.

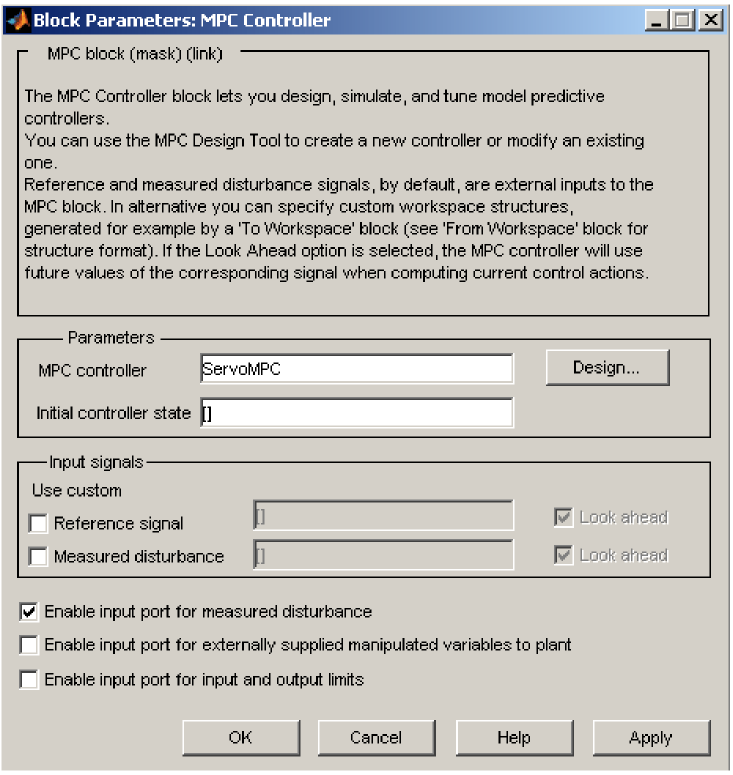
5.7 Description

MPCobj=mpc(plant) creates a MPC controller based on the discrete-time model model plant. The model can be specified either as an LTI object, or as an object in

System Identification Toolbox's format (IDMODEL object), see Using Identified Models.MPCobj=mpc(plant,ts) also specifies the sampling time ts for the MPC controller. A continuous-time plant is discretized with sampling time ts. A discrete-time plant is resampled if its sampling time is different than the controller's sampling time ts. If plant is a discrete-time model with unspecified sampling time, namely plant.ts=-1, then Model Predictive Control Toolbox assumes that the plant is sampled with the controller's sampling time ts.

MPCobj=mpc (plant, ts, p, m) also specifies prediction horizon p and control horizon m.

MPCobj=mpc(plant,ts,p,m,weights,MV,OV,DV) also specifies limits on manipulated variables (MV) and output variables (OV), as well as equal concern relaxation values, units, etc. Names and units of input disturbances can be also specified in the optional input DV. The fields of structures MV, OV, and DV are described in Manipulated Variables, OutputVariables,and DisturbanceVariables.



Block Parameters: MPC Controller

MPC block (mask) (link)

The MPC Controller block lets you design, simulate, and tune model predictive controllers.
You can use the MPC Design Tool to create a new controller or modify an existing one.
Reference and measured disturbance signals, by default, are external inputs to the MPC block. In alternative you can specify custom workspace structures, generated for example by a 'To Workspace' block (see 'From Workspace' block for structure format). If the Look Ahead option is selected, the MPC controller will use future values of the corresponding signal when computing current control actions.

Parameters

MPC controller: ServoMPC

Initial controller state: []

Input signals

Use custom

☐ Reference signal: [] ☑ Look ahead

☐ Measured disturbance: [] ☑ Look ahead

☑ Enable input port for measured disturbance

☐ Enable input port for externally supplied manipulated variables to plant

☐ Enable input port for input and output limits

Figure 5.17 Block parameter of MPC controller

Above block shows the block parameter of MPC controller. In this we design MPC controller, according to our information of the system.

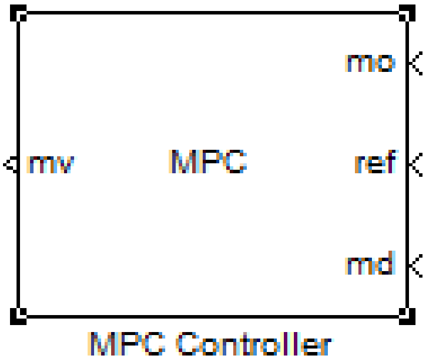


Figure 5.18 Block of MPC controller

MPC block has three inputs measured input, reference input and measured disturbance. Measured out put variable work as output signal. First we design MPC controller, for the given plant modal and then embed into the controller.

5.8 Simulation with PID controller (Step Input)

We will see the response by applying first Step input and then Ramp input. Block diagram for the simulation is given below, in which step input is applied.

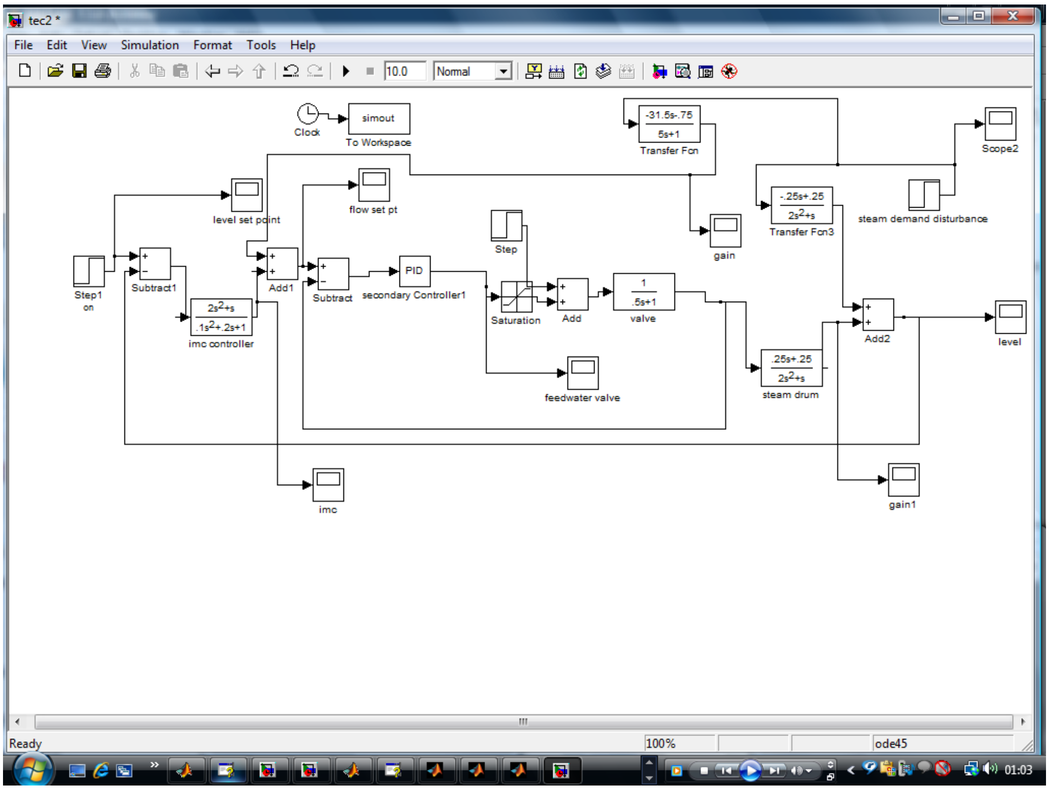


Figure 5.19 Unit step input is applied

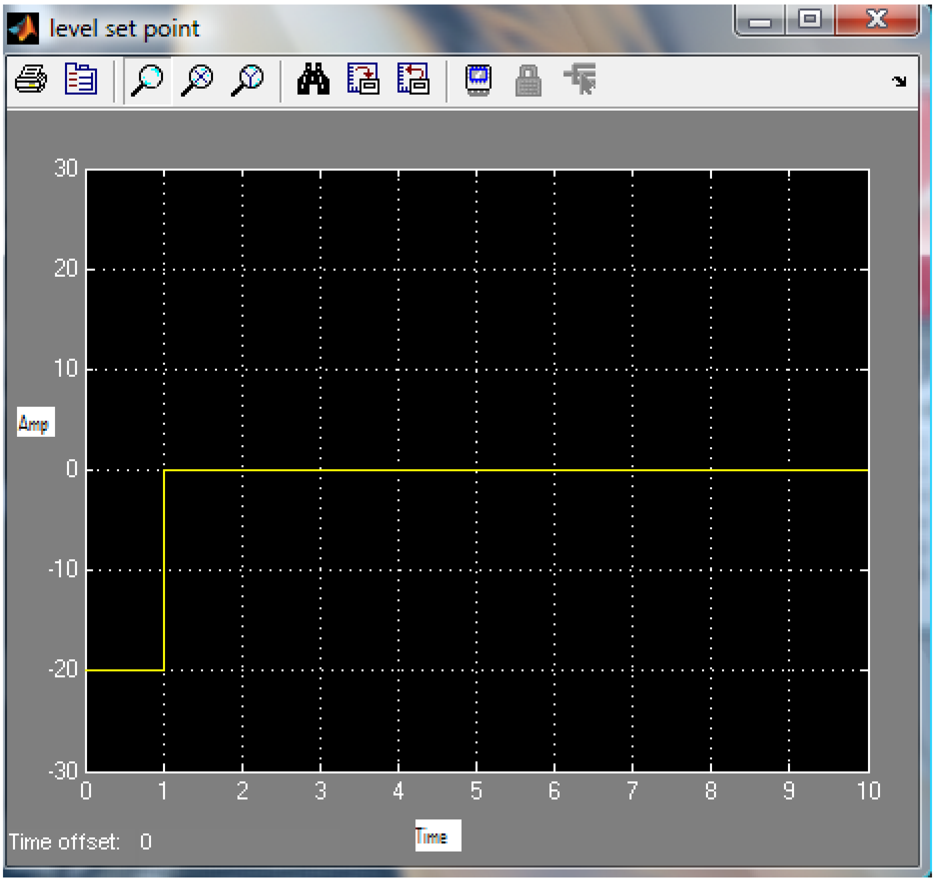


Figure 5.20 Step input response

It shows the step input response which is set point of level of boiler. Also the output of PID controller is given further. In the given scope of step parameter initial pint is taken as -20 and final value is 0, which is set point.

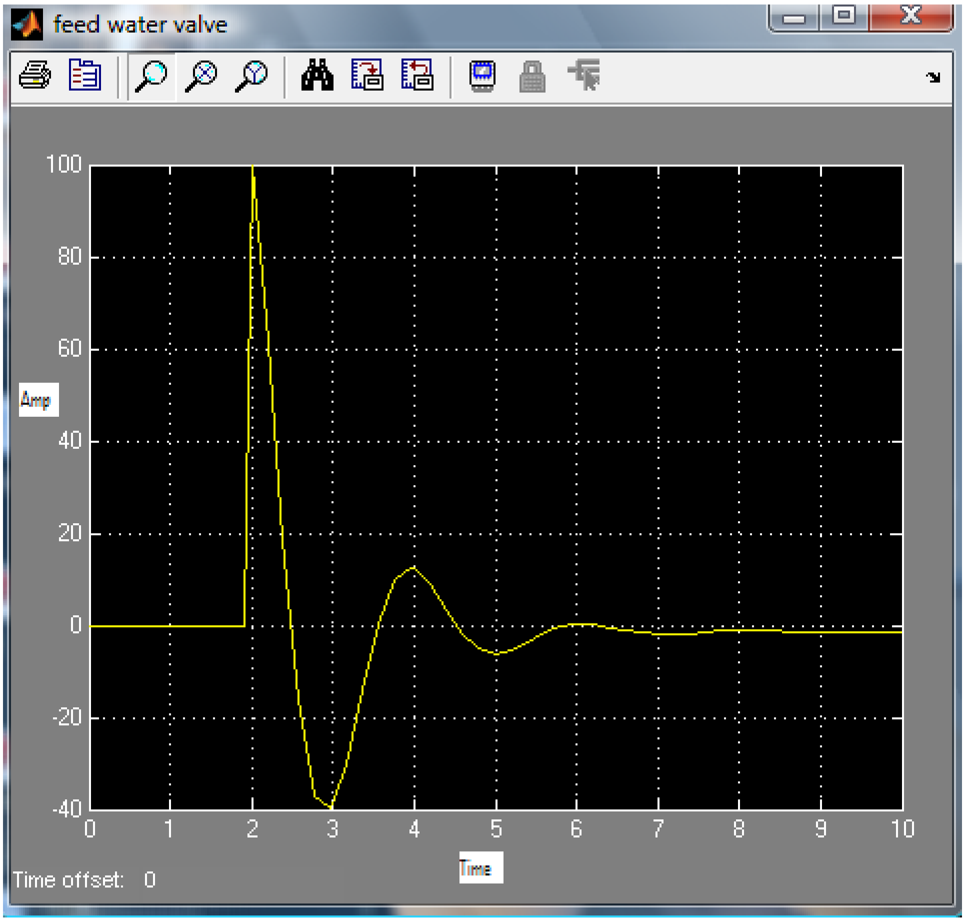


Figure 5.21 PID controller response with unit step input

It shows the response of the PID controller output. We will find Rise time, Peak time, Steady state error, Maximum overshoot and settling time.

Peak time (t_p) =0.705

Rise time (t_r) =0.521

Settling time (t_s) =2.455

Maximum overshoot (M_p) =32%

Steady state error (e_{ss}) =1.72

5.9 Simulation using Fuzzy controller (Step Input)

Now step input is applied on System with Fuzzy controller, response is given as under

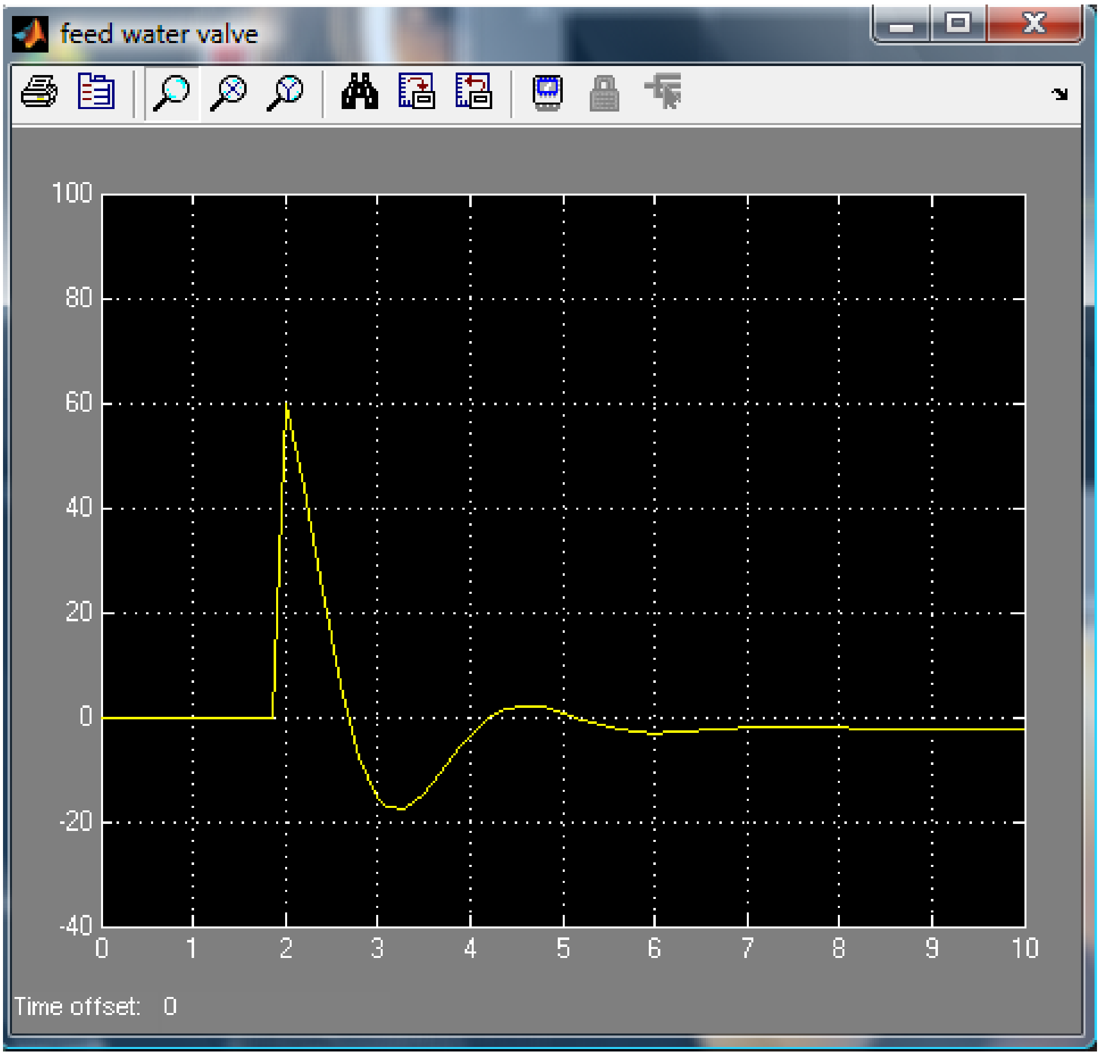


Figure 5.22 Fuzzy controller response with unit step input

Again we will find all the parameter which is given below

Peak time (t_p) =0.523

Rise time (t_r) =0.32

Settling time (t_s) =1.98

Maximum overshoot (M_p) =25.4%

Steady state error (e_{ss}) =1.02

5.10 Simulation using MPC Controller (Step Input)

Now system will simulate with MPC, Modal predictive controller. When unit step input is applied, response is give as under

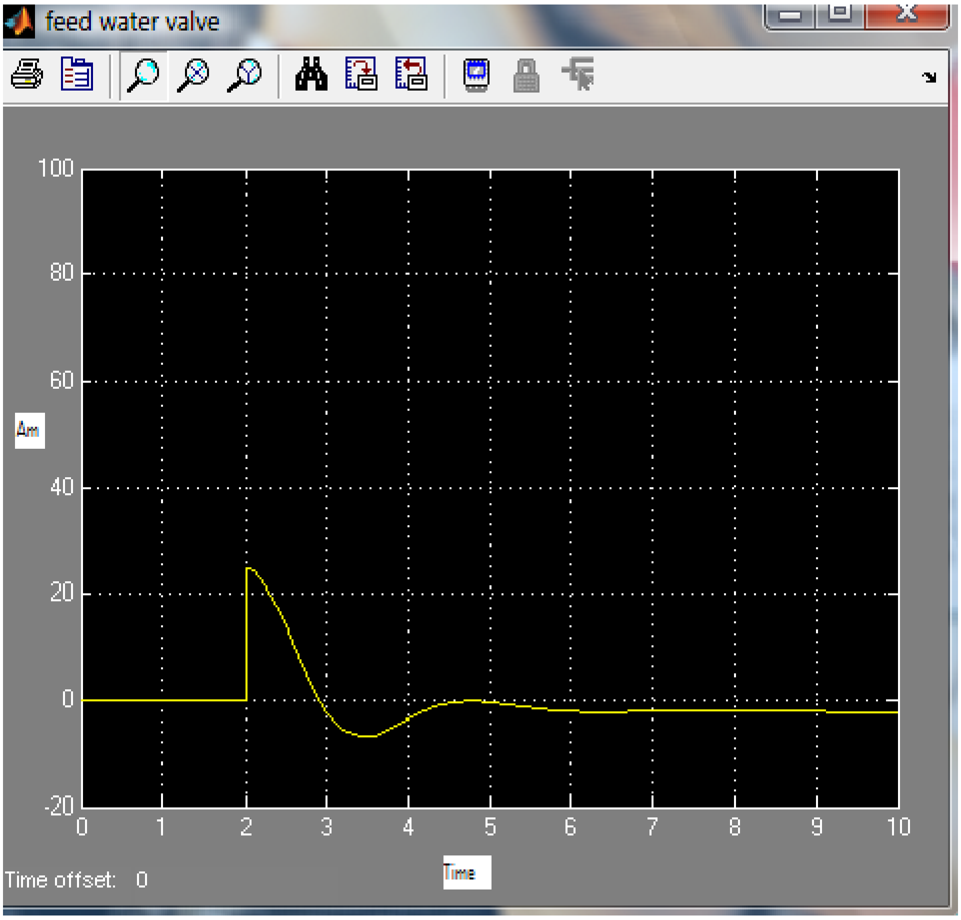


Figure 5.23 MPC controller response with unit step input

Peak time (t_p) =0.410

Rise time (t_r) =0.245

Settling time (t_s) =1.21

Maximum overshoot (M_p) =16.4%

Steady state error (e_{ss}) =0.64

5.11 Simulation with PID controller (Ramp Input)

Unit ramp input is used to analyse the performance of system, with all three controller used separately. These controllers are secondary controller which is much faster than the primary one that is IMC controller.

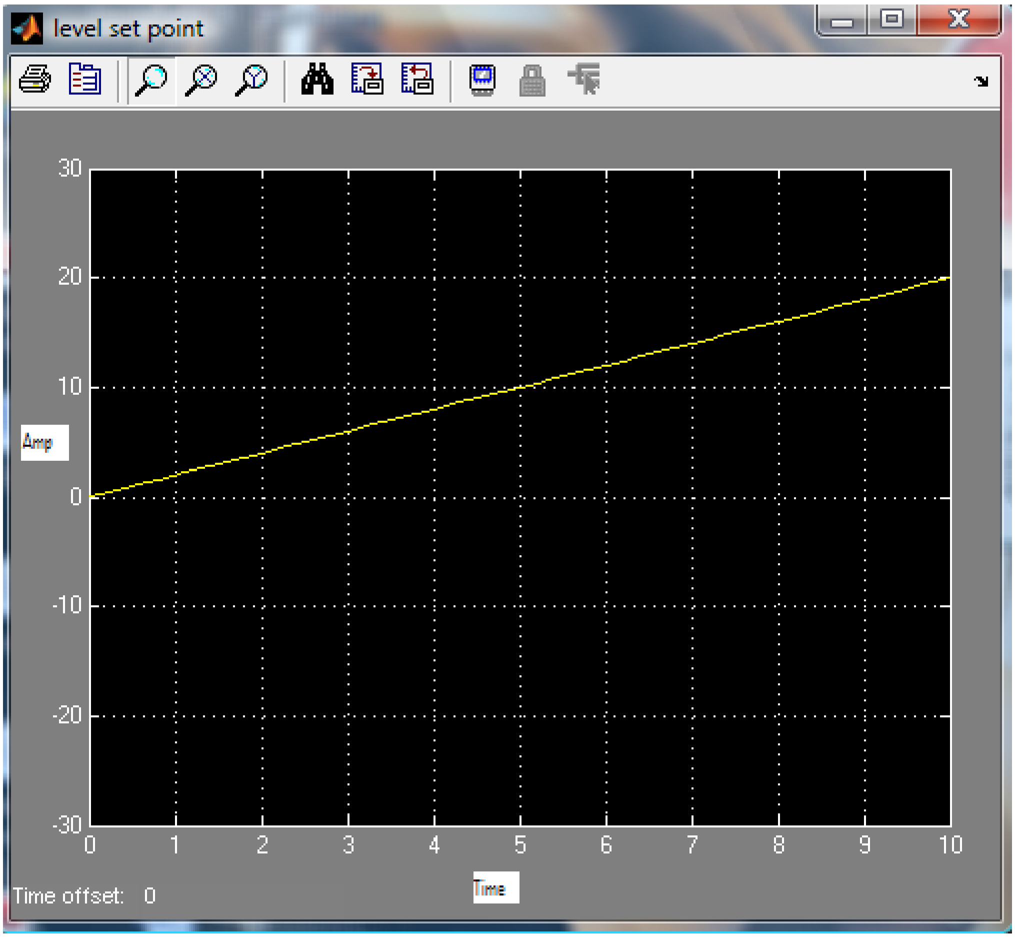


Figure 5.24 Unit ramp response with Fuzzy controller

Above shows the response of unit ramp, which is set point of system. Slope is taken as 2, initial input is zero and initial output is also zero. After simulating by giving ramp input the response of different controller is given. We will find Settling time (t_s) and steady state error (e_{ss}).

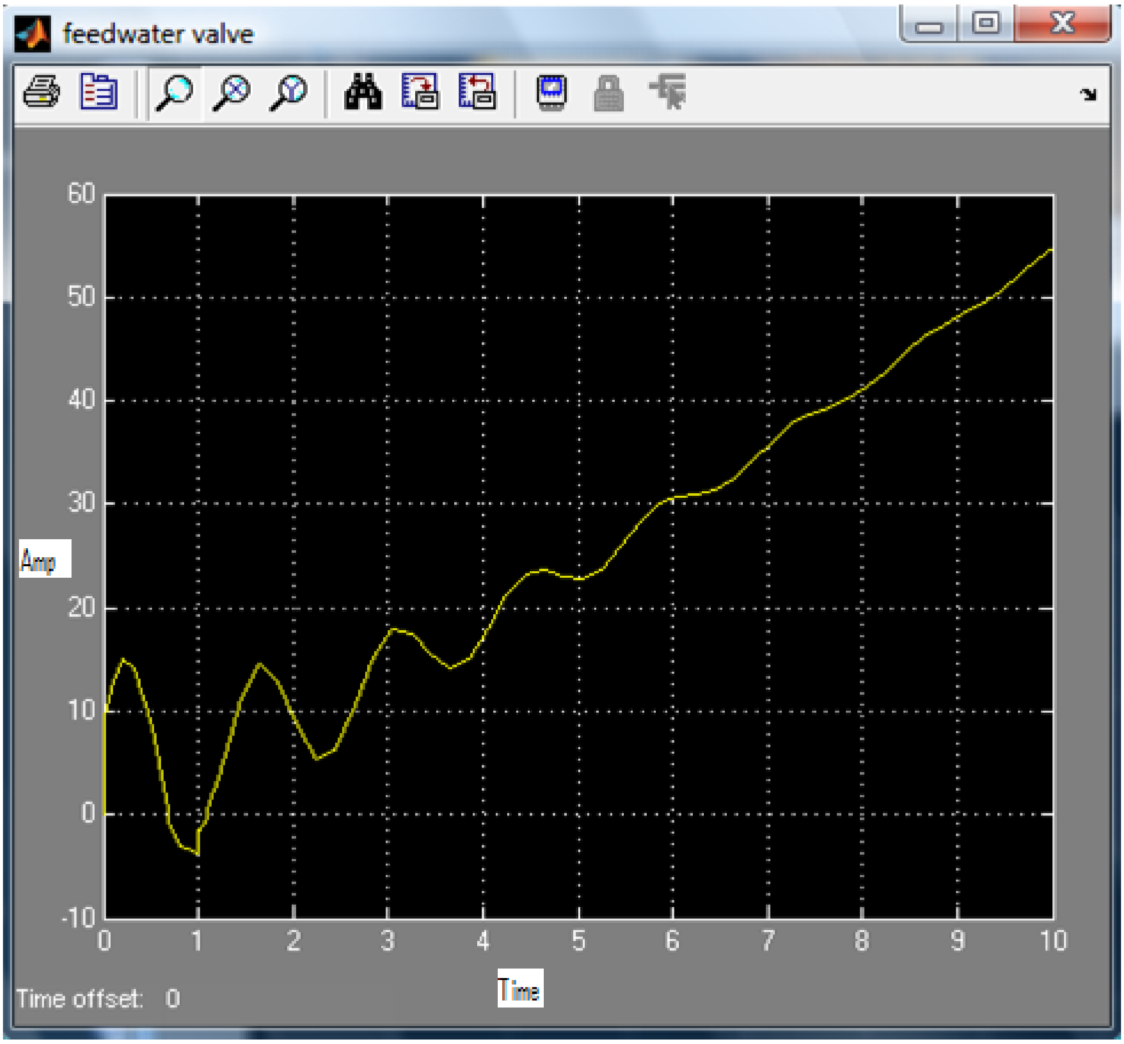


Figure 5.25 PID controller response with ramp input

Above scope shows the response of PID controller when Unit Ramp input is given as a set point. There is error occur initially in this case, then it settled slowly. This is further removed when Fuzzy controller is applied and then MPC.We will find here Settling time (t_s) and Steady state error (e_{ss}).

Settling time (t_s) =1.94

Steady state error (e_{ss}) =3.46

Now after applying Unit ramp as set point the response of different controller have different settling time and steady state error. Fuzzy response is improved over PID, but MPC has got good accuracy then both.

5.12 Simulation with Fuzzy controller (Ramp Input)

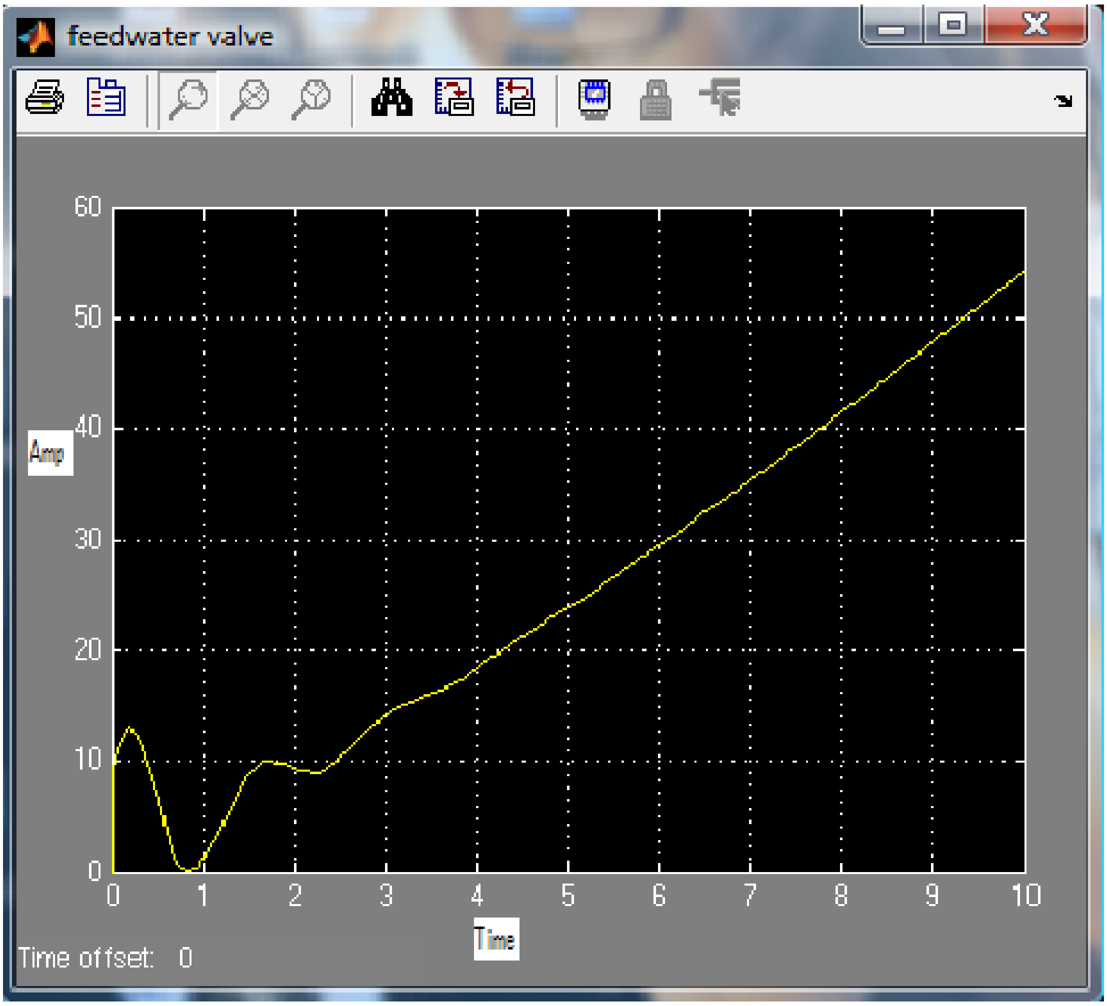


Figure 5.26 Fuzzy controller response with ramp input

Above scope shows the response of Fuzzy controller, according to our rule base, the rule fire and appropriate result occur when Unit Ramp input is given as a set point. There is less error than with PID occur initially in this case, and then it settled slowly. For this case Settling time (t_s) and Steady state error (e_{ss}) will be calculated as

Settling time (t_s) =1.12 sec

Steady state error (e_{ss}) =2.3

5.13 Simulation with MPC controller (Ramp Input)

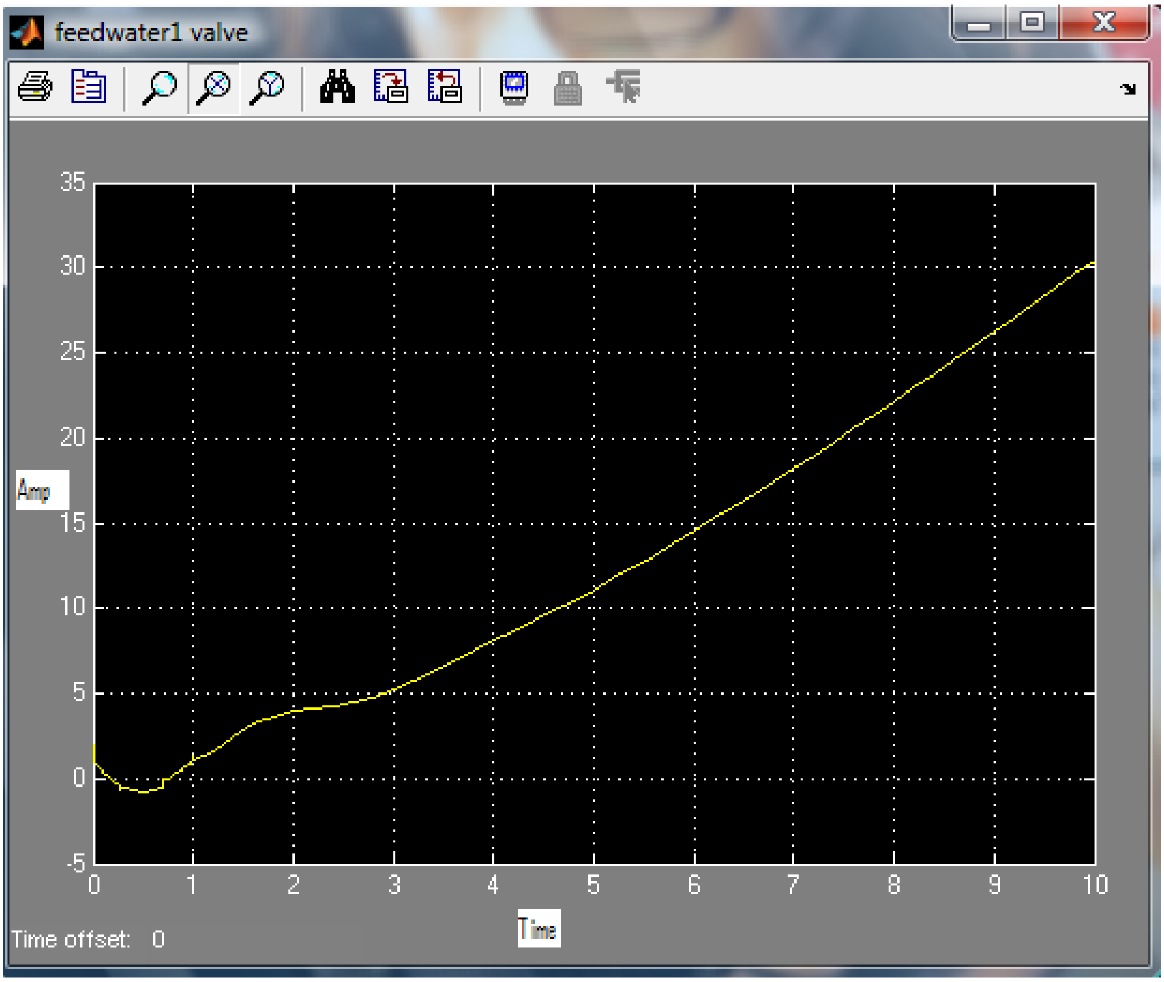


Figure 5.27 MPC controller response with ramp input

Above scope shows the response of MPC controller and appropriate result occur when Unit Ramp input is given as a set point. There is less error than with PID and Fuzzy controller Errors occur initially in this also, but settled quickly. For this case Settling time (t_s) and Steady state error (e_{ss}) will be calculated as

Settling time (t_s) =0.86 sec.

Steady state error (e_{ss}) =0.521

CHAPTER 6

RESULT AND DISCUSSION

This chapter presents the result of response of controller we have taken for analysis, using simulation process. As discussed in previous chapter the simulation block diagram are implemented under MATLAB environment using three different controller as PID controller, Fuzzy Logic controller & MPC (Modal Predictive controller).These work as secondary controller whereas primary controller was taken as IMC controller. These controllers have different responses for the input taken as Unit step and then with Unit ramp. After simulation we have find that all these controller have different value of parameters such as peak time(t_p),settling time(t_s),rise time(t_r),maximum overshoot(M_p),steady state error(e_{ss}).

In the analysis we have seen that more accurate result came using Fuzzy controller over PID controller, further better result got in case of MPC controller. Below table show the comparison between the parameters of different input with different controllers.

Table 6.1 Value of parameters when Unit step is applied

Controllers / Parameters	PID Controller	Fuzzy Logic Controller	MPC Controller
Peak Time(t_p)sec.	0.705	0.52	0.41
Rise Time(t_r)sec.	0.521	0.32	0.24
Settling Time(t_s)sec.	2.45	1.98	1.21
Maximum Overshoot(M_p)	32%	25.4%	16.4%
Steady State Error(e_{ss})	1.72	1.12	0.64

First Unit step input is applied to the system as the set point. From the above table we can see the advantage of Fuzzy over PID and also MPC got good accuracy than both of these controllers.

Now after applying Unit ramp as set point the response of different controller have different settling time and steady state error. Fuzzy response is improved over PID, but MPC has got good accuracy then both of these tables for the different response is given as under.

Table 6.2 Value of parameters when Ramp input is applied

Controllers / Parameters	PID controller	Fuzzy Logic Controller	MPC controller
Settling Time(t_s)sec.	1.94	1.12	0.86
Steady state error(e_{ss})	3.46	2.3	0.521

From the result obtained we can say that PID controllers have some drawbacks that limit their effectiveness they work best with systems that have only one input and output (single input, single output − SISO).With these systems, we have only one variable to control and only one actuation to apply. Another challenge for PID controllers (and for every control algorithm) is that the plant we need to control might not behave in a linear fashion. In other words, the output for a given input does not exhibit a linear response. Some examples of nonlinearity are dead zones, saturations, and hysteresis. Another challenge is that plant dynamics might also change over time. This can happen due to changes on the plant loads, normal wear and tear, or mechanical effectiveness in mechanical elements. Due to this settling time of PID controller is more than that of Fuzzy controller and MPC controller, also it have maximum overshoot. To compensate for plant behaviour changing over time, we have better controller as Fuzzy controller and MPC controller. Fuzzy controller can admit a high degree of parallel implementation, and can tolerate uncertainty in the system also they are nonlinear and adaptive. It has better settling time and less overshoot than PID but its response is not as better than as with MPC controller. We can see the data from the table.MPC controller can adjust the control action before a change in the output set point actually occurs. This predictive ability, when combined with traditional feedback operation, enables a controller to make adjustments that are smoother and closer to the optimal control action values. We can say that to reach the set point when ramp input is applied MPC controller has taken less time than PID and Fuzzy controller. Also steady error is less in case of MPC controller.

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

Conclusion

The use of MPC controller and Fuzzy controller improves the performance to great extent.MPC controller shows better performance than both of these controller.PID controller and Fuzzy controller’s settling time, rise time and peak time in case of MPC is good than others .Also it has got low Maximum overshoot .We can say for the non linear plant or when the plant response is changing with time, or there is uncertainty we should use Fuzzy logic controller. For the disturbance to occur it should be also taken into account, it can be easily removed, and the system gives better response using MPC controller. MPC controller can adjust the control action before a change in the output set point actually occurs. Hence from the given data we conclude the MPC is better then Fuzzy controller and PID controller.

Future Scope

It has been discussed in the previous chapter about the performance of MPC controller, FLC controller and PID controller. Each have different responses for the step and ramp input. Further for the future perspective we can use IMC-based PID controller for the unstable process, a pure PID controller structure will only be appropriate for a limited class of systems, since additional filtering action is introduced, thus it will first be of interest to determine sufficient conditions for the IMC controller to approximation a PID structure in cascade with a filter. It can be also applied in ANFIS Adaptive Neural Fuzzy Inference System.

REFERENCES

[1] Dwarakanath M.H., Dembart B., Erisman A.M., Hemmaplardh K., Manke J.W., ‘A generalised methodology for modelling system components in power system dynamic simulation’, *IEEE Trans. Power Apparatus and Systems*, Vol. PAS-101, NO. 1, 1982, pp. 136-146.

[2] Nornura, M. and Y. Sato. "Adaptive Optimal Control of !steam Temperatures for Thermal Power Plants," */€"€E Trans. on Energy Conversion,* Vol. 4,No. 1, pp. 25-33, March 1988.

[3] J.A.Bernard”Use of rule based system for process Control”, IEEE contr.syst Mag, vol.8, no.5, pp 3-13 1988

[4] Hoglg, B. W. and N. M. El-Rabaie. "Generalized Predictive Control of Steam Pressure in a Drum Boiler," */€E Trans, on Energy Conversion,* Vol. *5*, No. 3, pp. 485-492, Sept. 1990.

[5] Cheres, E. "Small and Medium Size Drum Boiler Model Suitable for Long Term Dynamic Response," *IEEE Trans. on Energy Conversion*, Vol. *5*, No. 4, pp. 686-692, Dec. 1990.

[6] B. W. Hogg and N. M. El-Rabie, “Generalized predictive control ofsteam pressure in a drum boiler,” *IEEE Trans. Energy Convers.*, vol. 5, no. 3, pp. 485–492, Sep. 1990.

[7] Lee, C.C., “Fuzzy Logic in Control System: Fuzzy Logic Controller - Part I and Part II”, IEEE Transactions on SMC, 20, pp.404-435, 1990.

[8] D. Driankov, H. Hellendoorn, and M. Reinfrank.” An Introduction to Fuzzy Control”. Springer-Verlag, New York, 1993

[9] Zafiriou, E., “Stability of Model Predictive Control with Volterra Series”, *AIChE Annual Meeting*, St. Louis (1993).

[10] Rawlings, J. B., E. S. Meadows, and K. R. Muske, “Nonlinear Model Predictive Control: A Tutorial and Survey”, *Proceedings of ADCHEM ’94*, 203-214, Kyoto, Japan (1994).

[11] Radenkovic, M. S., and B. Erik Ydstie, “Using Persistent Excitation with Fixed Energy to Stabilize Adaptive Controllers and Obtain Hard Bounds for the Parameter Estimation Error”, *SIAM J. Contr. And Optimization*, **33**, 4, 1224-1246 (1995).

[12] Kazuo Tanuka, Manabu Sano and Hiroyuki Watanabe “Modeling and control of carbon Mono oxide concentration using neuro fuzzy techinques ” IEEE transaction on fuzzy system vol. 3,August 1995

[13] T. Ross. “Fuzzy Logic in Engineering Applications”. McGraw-Hill, New York, 1995

[14] Driankov, D.,Hellendoorn, H. and Reinfrank,M. (1996). *$Q LQWURGXFWLRQ WR IX]]\ FRQWURO*, second edn, Springer-Verlag, Berlin

[15] Qiao,W. and Mizumoto,M. (1996). PID type fuzzy controller and parameters adaptive method, *)X]]\ 6HWV DQG 6\VWHPV* (1996).

[16] Jan Jantzen” Design Of Fuzzy Controllers” Technical University of Denmark, Department of Automation, Bldg 326, DK-2800 Lyngby, DENMARK.
Tech. report no 98-E 864 (design), 19 Aug 1998.

[17] Flynn, M. E. and O'Malley, M. J., A drum boiler model for long term power system dynamic simulation. IEEE Trans. Power Appar. Syst. 14~1!, 209–217~1999!.

[18] Peter Eserin" Application of Canonical Variate Analysis to the Dynamical Modeling and Control of Drum Level in an Industrial Boiler" San Diego, California June 1999

[19] Bordeneuve-Guibe, J.Vaucoret,C. 2002-08-07"Robust multivariable predictive control" April 2001

[20] Mohanlal, P.P. Kaimal, M.R. Vikram " Decision and Control" Proceedings of the 41st IEEE Conference Sarabhai Space Centre, Trivandrum, India on Volume3 page 3255 – 3260, Dec. 2002

[21] Donald l. Basham, p.e dr. James w Wright, p.e. ufc 4-010-01 8 October 2003

[22] Reza Ezuan Samin, Mohd Syakirin Ramli " Performance Comparison of PD-type Fuzzy Logic Controller of USBM Simplified Model"(2003).

[23] Min Xu,a Shaoyuan Li,a,* Wenjian Caib" Cascade generalized predictive control strategy for boiler drum level" 399–411 December 2004!

[24] N.S.Nise, Control System Engineering, John Wiley & Sons, 4th Edition, pp. 764-767, 2004

[25] Shaoyuan Li, *Senior Member, IEEE*, Hongbo Liu, Wen-Jian Cai, Yeng-Chai Soh, and Li-Hua Xie" A New Coordinated Control Strategy for Boiler-Turbine System of Coal-Fired Power Plant" IEEE TRANSACTIONS ON CONTROL SYSTEMS TECHNOLOGY, VOL. 13, NO. 6, NOVEMBER 2005

[26] T.R. Rangaswamy, J. Shanmugam, and K.P. Mohammed" Adaptive Fuzzy Tuned PID Controller for Combustion of Utility Boiler"(2005*)*

[27] Yonghong Huang'1, Nianping Li2, Yangchun Shil, Yixun Yil" Genetic Adaptive Control for Drum Level of a Power Plant Boiler" "Computational Engineering in Systems Applications"(CESA), October 4-6, 2006, Beijing, China

[28] Enrique Arriaga-De-Valle Graciano Dieck-Assad Electrical Engineering Department ITESM, Monterrey Campus2501 E. Garza Sada Monterrey, NL Mexico, CP 64849,, Volume 82 , Issue 12 (December 2006) table of contents Pages 841-850,2006

[29**]** Rosehart, W Kennedy, W." Power Plants and Power Systems Control, Volume # 5 |, Ecole Nationale Superieure en Genie des Systemes Industriels, Canada 2008**"**