

# **INTERNET BASED DATA LOGGING AND SUPERVISORY CONTROL OF BOILER DRUM LEVEL USING LABVIEW**

*A Thesis Submitted for Partial Fulfilment  
of the Requirement for the Award of the Degree of*

**Masters of Technology  
in  
Electronics and Instrumentation Engineering**

by

**ROOPAL AGRAWAL  
Roll No: 210EC3325**



**Department of Electronics & Communication Engineering  
National Institute of Technology, Rourkela  
Odisha-769008, India  
May 2012**

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Under the Guidance of

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May 2012**



NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

## **CERTIFICATE**

This is to certify that the project report titled “**Internet Based Data Logging and Supervisory Control of Boiler Drum Level Using LabVIEW**” submitted by **Roopal Agrawal** (210EC3325) in the partial fulfilment of the requirements for the award of Master of Technology Degree in the Electronics and Instrumentation Engineering during Session 2010-2012 at National Institute of Technology, Rourkela (Deemed University) and is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

Date:

**Dr. U. C. PATI**  
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*Dedicated*  
*to*  
*My Parents*

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# Abstract

This work describes a framework of a Internet based data logging and supervisory control of boiler drum level system. The design and implementation of this process is done by the LabVIEW software. The data of the process variables (Temperature and Level) from the boiler system need to be logged in a database for further analysis and supervisory control. A LabVIEW based data logging and supervisory control program simulates the process and the generated data are logged in to the database as text file with proper indication about the status of the process variable (normal or not normal).

Three different types of boiler drum level control system are designed in the *Circuit Design and Simulation* toolkit of LabVIEW. This work provides the knowledge about the Fuzzy Adaptive PID Controller and the various PID controller design methods such as Zeigler-Nichol method, Tyreus-Luyben method, Internal Model Control (IMC). Comparative study is made on the performance of the PID and Fuzzy Adaptive PID controller for better control system design.

The internet plays a significant and vital role in the real time control and monitoring of the industrial process. Internet based system control and monitor the plant system remotely from anywhere without any limitation to any geographical region. Internet based boiler control system is developed by a *Web Publishing* tool in LabVIEW. The use of internet as a communication medium provides the flexible and cost-effective solution. Now, to analyse the performance of boiler drum level control system, Internet based data logging and supervisory control system is designed. Hence, anyone can control and monitor the boiler plant globally.

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## LIST OF ACRONYMS

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PI	Proportional Integral
PD	Proportional Derivative
PID	Proportional Integral Derivative
LabVIEW	Laboratory Virtual Instrumentation Engineering Workbench
VI	Virtual Instruments
IMC	Internal Model Control
ADC	Analog Digital Converter
SCADA	Supervisory Control and Data Acquisition
GUI	Graphical User Interface
HTTP	Hypertext Transfer Protocol
IEEE	Institute of Electrical and Electronics Engineers

# **Chapter 1**

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## **Introduction**

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# INTRODUCTION

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In this chapter, the overview of the Internet based boiler drum level control system is described. Literature survey of this work has been discussed. The objective of the thesis is explained. At the end organization of thesis has been presented.

## 1.1 Overview

Boiler is defined as a closed vessel in which steam is produced from water by the combustion of fuel. Generally, in boilers steam is produced by the interaction of hot flue gases with water pipes which is coming out from the fuel mainly coal or coke. In boilers, chemical energy of stored fuel is converted into the heat energy and this heat energy is absorbed by the water which convert them into a steam.

Due to poorly understand the working principles; boilers have many serious injuries and destruction of property. It is critical for the safe operation of the boiler and the steam turbine. Too low a level may overheat boiler tubes and damage them. Too high a level may interfere with separating moisture from steam and transfers moisture into the turbine, which reduces the boiler efficiency. Various controlling mechanism are used to control the boiler system so that it works properly.

To maintain the boiler drum level constant proper data monitoring and recording is required. The process of collecting data through sensors, analyse the data and save the data in computer is called data logging. The data can be temperature, pressure, displacement, flow, voltage, strain, current, power or any wide range of process variables. Data logging is commonly used in monitoring system where there is the need of collecting information faster than a human can possible collect the information over a period of time. It has the ability to automatically collect data on a 24 hour basis. Real world data logging applications are typically more involved than just acquiring and recording signals, typically involving some combination of online analysis, offline analysis, display, report generation and data sharing.

In recent years, Internet-based control systems have gained considerable attention in science and engineering, since they provide a new and convenient unified framework for system control applications. Internet based Supervisory Control and Data Acquisition (SCADA), utilizes the public Internet as a communication medium. It facilitates with the versatile supervision and control, not necessarily from the remote control centre, but from any part of the world with facilities of World Wide Web.

## **1.2 Literature Survey**

Min Xu, Shaoyuan Li and Wenjian Cai have proposed a cascade model predictive control scheme for boiler drum level control [1]. By employing generalized predictive control structures for both inner and outer loops, measured and unmeasured disturbances can be effectively rejected, and drum level at constant load is maintained. In addition, non minimum phase characteristic and system constraints in both loops can be handled effectively by generalized predictive control algorithms. The algorithm has also been implemented to control a 75-MW boiler plant, and the results show an improvement over conventional control schemes.

Yonghong Huang, Nianping Li, Yangchun Shil and Yixun Yil have proposed about the Adaptive control strategy to regulate the drum-level of a power plant boiler [2]. 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.

In 2010 Yuanhui Yang, Wailing Yang, Mingchun Wu, Qiwen Yang and Yuncan Xue have presented an adaptive fuzzy PID controller [3]. Its functionality is divided into three operating units which are the proportional operating unit, the integral operating units and the derivative

operating unit. The inputs of the controller are composed of two kinds of signal. The main input signal is the weighted system error and the weights are the traditional PID parameter with fixed gains tuned in a traditional way. The auxiliary input signal is produced by a fuzzy logic controller. The output of the controller is adjusted implicitly and adaptively.

Zafer Aydogmus and Omur Aydogmus have presented a Web-based remote access real-time laboratory using SCADA (supervisory control and data acquisition) control [4]. The control of an induction motor is used to demonstrate the effectiveness of this remote laboratory, using real instruments. A programmable logic controller (PLC) was programmed to control the operation of the system and a SCADA system was installed to monitor and control of the process.

Subhransu Padhee and Yaduvir Singh give an overview of data acquisition, data logging and supervisory control system of a plant consisting of multiple boilers [5]. Data acquisition, data logging and supervisory control are the basic building blocks of plant automation. This paper takes a case study of plant consisting of multiple boilers where multiple process variables of the boilers need to be acquired from the field and monitored. The data of the process variables needs to be logged in a database for further analysis and supervisory control.

### **1.3 Objective**

The objective of this work is to design a Internet based data logging and supervisory control of boiler drum level control system. Data logging is a very common measurement application for recording of physical or electrical parameters over a period of time. This electrical parameter is generated from the boiler drum level control process. The data of the process variables needs to be logged in a database for further analysis and supervisory control. A LabVIEW based data logging and supervisory control program simulates the process and the generated data are logged in to the database with proper indication about the status of the process variable.

Internet-based control systems have been developed by means of extending discrete control systems. The use of the Internet as a communication medium provides cost-effective, flexible

and easy-to- access distributed control systems that are not limited to any geographical region. Internet-based control systems are characterized as globally remote monitoring by the Internet.

## **1.4 Thesis Organization**

This thesis contains 6 chapters. Following the introduction, the rest of the thesis is organized as follows:

### **Chapter-2 Control Strategies of Boiler**

The basic of control strategies of boiler drum level control is discussed. Controller is used to control the process of boiler drum level control system. There are various PID control tuning methods such as Ziegler-Nichols method, Tyreus-Luyben method and Internal Model Control (IMC) are used to design the controller of boiler. Theory of Fuzzy Logic Controller is also explained.

### **Chapter-3 Boiler Drum Level Control System**

In this chapter, three different types of boiler are explained as Single element boiler drum level control, two element boiler drum level control and three element boiler drum level control. The parameters of boiler drum level control system are discussed. Simulation results of all the three types of boiler are shown with PID and Fuzzy Logic Control strategies. Comparison is shown in the performance of boiler with different control strategies.

### **Chapter-4 Data Logging and Supervisory Control**

This chapter explained the data acquisition, data logging and supervisory control of the boiler drum level control system. Simulation of data logging system is performed in the LabVIEW software. The generated result is logged into the database in Microsoft excel file.

## **Chapter-5 Internet Based Control System**

This chapter presents the basic concept of internet based control system. Web based boiler drum level control system is developed by *Web Publishing* tool in LabVIEW. The concept of web services is explained. Architecture of Client/Server based on Internet is described. Simulation has been performed and HTML file is created as a result.

## **Chapter-6 Conclusion**

The overall conclusion of the thesis is presented in this chapter. It also contains some future research topics which need attention and future investigation.

# **Chapter 2**

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## **Control Strategies of Boiler**

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## **CONTROL STRATEGIES OF BOILER**

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The introduction of three element boiler drum level control system is explained. The application of boiler drum level control system is discussed. The basic of control strategies of boiler drum level control is described. There are various PID control tuning methods such as Ziegler-Nichols method, Tyreus-Luyben method and Internal Model Control (IMC) which are used to design the controller of boiler. Theory of Fuzzy Logic Controller is also explained.

### **2.1 Three Element Control**

In the process industries, to control the three elements of boiler i.e. steam flow, drum level of water and feed water flow is required for the proper functioning of boiler. 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 variables will increase or decrease only with a change in flow.

To maintain the drum level at constant steam load, a controller has been designed to bring the drum up to the level of set point. In single-element control, only drum level measurement and a feed water control valve are required. The two-element drum level control uses two variables i.e. drum level and steam flow to manipulate the feed water control valve. The three-element drum level control uses three variables i.e. drum level, steam flow and feed water flow rate, to manipulate the feed water control valve as shown in Fig. 2.1.

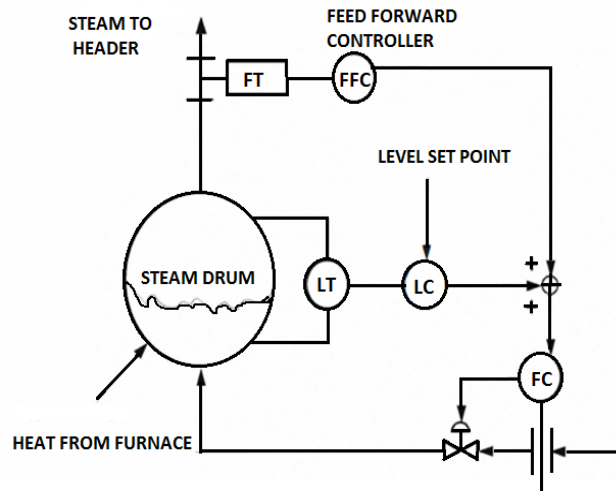


Figure 2.1 Three element boiler drum level control

## 2.2 Applications of Boiler

Boilers have many applications which are as follows:

- These can be used in stationary applications to provide heat, hot water and steam for domestic use in many industries.
- These can be used in mobile applications to provide steam for locomotion in applications such as trains, ships, and boats.
- Steam boilers are used as generators to produce electricity in the energy business. These are also used in agriculture as well for soil steaming.
- These can be used in heating systems or for cement production.
- These can be used in textile industries for bleaching and many other industries like sugar mills and chemical industries.

## 2.3 Control Strategies

Control strategies are necessary for any system to perform accurately. Some of these are given below.

### 2.3.1 PID Controller

A Proportional-Integral-Derivative (PID) controller is a general feedback control loop mechanism widely used in industrial process control systems. A PID controller corrects the error between a measured process variable and the desired set point by calculating the value of error. The corrective action can adjust the process rapidly to keep the error minimal [6].

The PID controller separately calculate the three parameters i.e. the proportional, the integral, the 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 as past error. The derivative value determines the reaction based on the rate at which the error has been changing as a future error. By tuning these three constants in the PID controller algorithm, the controller can provide control action designed for specific process control requirements [7].

Some applications may require only one or two parameters of the PID controller to provide the appropriate control on system. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. This is achieved by setting the gain of undesired control outputs to zero. PI controllers are very 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 control action.

Following are the process used to determine the PID gain parameter:

#### 2.3.1.1 Ziegler–Nichols Method

This method is introduced by John G. Ziegler and Nathaniel B. Nichols [8]. In this method, the  $K_i$  and  $K_d$  gains are first set to zero. The  $P$  gain is increased until it reaches the ultimate gain  $K_u$ , at which the output of the loop starts to oscillate.  $K_u$  and the oscillation period  $P_u$  are used to set the gains as shown in Table 2.1.

Table 2.1 Ziegler-Nichol Parameter

Control Type	$K_p$	$K_i$	$K_d$
P	$0.50 K_u$	-	-
PI	$0.45 K_u$	$1.2 K_p / P_u$	-
PID	$0.60 K_u$	$2 K_p / P_u$	$K_p P_u / 8$

These gains apply to the ideal, parallel form of the PID controller. When applied to the standard PID form, the integral and derivative time parameters  $T_i$  and  $T_d$  are only dependent on the oscillation period  $P_u$ .

### 2.3.1.2 Tyreus-Luyben Method

This method is introduced by Tyreus-Luyen. In this method, the  $K_i$  and  $K_d$  gains are first set to zero. The  $P$  gain is increased until it reaches the ultimate gain  $K_u$ , at which the output of the loop starts to oscillate.  $K_u$  and the oscillation period  $P_u$  are used to set the gains as shown in Table 2.2.

Table 2.2 Tyreus-Luyben Parameter

Control Type	$K_p$	$K_i$	$K_d$
PI	$0.3125 K_u$	$K_p / 2.2 P_u$	-
PID	$0.4545 K_u$	$K_p / 2.2 P_u$	$K_p P_u / 6.3$

### 2.3.1.3 Internal Model Control (IMC)

The IMC based PID structure uses the process model as in IMC design. In the IMC procedure, the controller  $Q_c(s)$  is directly based on the invertible part of the process transfer function. The IMC results in only one tuning parameter which is filter tuning factor but the IMC based PID tuning parameters are the functions of this tuning factor. The selection of the filter parameter is directly related to the robustness. IMC based PID procedures uses an approximation for the dead time.

### 2.3.2 Fuzzy Adaptive PID Control

Based on the process knowledge, an intelligent control technique that is Fuzzy Adaptive PID Control is discussed. The structure of fuzzy adaptive PID controller is shown in Fig. 2.2. It mainly consists of two parts, one is the conventional PID controller and the other is fuzzy logic controller. In this work, two input and three output fuzzy adaptive PID controller is designed. The inputs are the error and the error rate (change in error) and outputs are the values of  $K_p$ ,  $K_i$  and  $K_d$ . The objective is to find the fuzzy relations among  $K_p$ ,  $K_i$ ,  $K_d$ , error and error rate. With continuous testing, the three output parameters are adjusted so as to achieve good stability. Variable PID controller adds the output value of the fuzzy controller and default PID values [9].

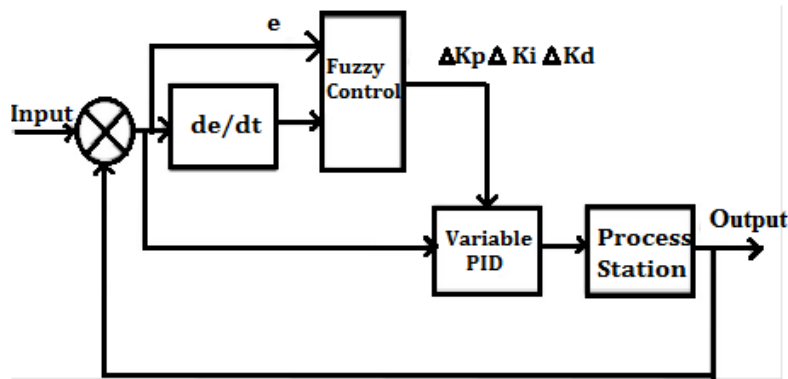


Figure 2.2 Structure of Fuzzy Adaptive PID

#### 2.3.2.1 Design of Fuzzy Adaptive PID

Fuzzy controller is a special fuzzy system that can be used as a controller component in a closed-loop system. It includes the fuzzifier, fuzzy rule base, process knowledge and FL rules, fuzzy inference engine and de-fuzzifier. The fuzzifier is the plant to fuzzy logic system interface and performs a mapping from real-valued variables into fuzzy variables. The fuzzy rule base consists of a collection of fuzzy rules. The knowledge base contains the experienced knowledge of the flow process station. Data base contains the membership function of every linguistic variable.

Control rules are described by the data base. The defuzzifier is the fuzzy logic system-to-plant interface and performs a mapping from fuzzy variables to real-valued variables.

### 2.3.2.2 Membership Function

The membership function used by fuzzy controller is the triangular membership function. The input ranges is from -1 to +1 and the fuzzy subset are Negative Big, Negative medium, Negative small, Zero, Positive small, Positive medium and Positive Big respectively termed as NB, NM, NS, ZO, PS, PM and PB. The performance of the controller depends on the quantization factor and the scaling factor.

### 2.3.2.3 Control Rules of the Fuzzy Controller

The control rules are designed to achieve the best performance of the fuzzy controller. In this work 49 control rules are adopted. These rules are given in the Table 2.3, 2.4 and 2.5.

Table 2.3  $K_p$  Fuzzy Control Rule

EC E	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Table 2.4  $K_d$  Fuzzy Control Rule

EC E	NB	NM	NS	ZO	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZO
NS	ZO	NS	NM	NM	NS	NS	ZO
ZO	ZO	NS	NS	NS	NS	NS	ZO
PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

Table 2.5  $K_i$  Fuzzy Control Rule

EC \ E	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	ZO	PS	PS
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PS	PM	PB
PM	ZO	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

Using this control rules, fuzzy.fs file is created. This control rules are generated using the *Fuzzy System Designer* toolbox available in LabVIEW. The membership function with the mentioned fuzzy subsets and the control rules form the fuzzy controller. This .fs file is called in the simulation environment of LabVIEW as a sub VI. The inference engine used here is the Mamdani Inference engine. The technique proposed in this work has been tested on a *Circuit Design and Simulation* toolkit based on LabVIEW .

## 2.4 NI-LabVIEW

National Instrument's LabVIEW is a graphical development environment for creating flexible, measurement and control applications rapidly at minimal cost. With LabVIEW, engineers and scientists interface with real-world signals, analyse data for meaningful information and share results. LabVIEW makes development very fast and easy for all users.

### 2.4.1 Key Features of LabVIEW

- Graphical Programming
- Built-in measurement and control function
- Multiple development tools
- Wide array of computing targets

The main programming section of LabVIEW is a Virtual Interface (VI) and a corresponding block diagram. Programming for the VI is done using control palette which contains several controls and indicators. Similarly, the corresponding block diagram is programmed using the function palette.

# **Chapter 3**

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## **Boiler Drum Level Control System**

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# **BOILER DRUM LEVEL CONTROL SYSTEM**

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In this chapter, three different types of boiler i.e. Single element boiler drum level control, two element boiler drum level control and three element boiler drum level control are explained. The parameters of boiler drum level control system are discussed. Simulation results of all the three types of boiler are shown with PID and Fuzzy Logic Control strategies. Comparison of the boiler performance through different controller are discussed.

## **3.1 Introduction**

Boiler is a closed vessel in which water or other fluid is heated. The heated or vaporised fluid exits the boiler for use in various process or heating applications. It is a device used to create steam by applying heat energy to water. A boiler must be designed to absorb the maximum amount of heat released in the process of combustion of fuel. The heat is transferred to the boiler water through radiation, conduction and convection. The relative percentage of each is dependent upon the type of boiler, the designed heat transfer surface and the fuels [10].

Drum Level Control Systems are used extensively throughout the process industries. It is used to control the level of boiling water contained in boiler drums and provide a constant supply of steam. If the level is too high, flooding of steam purification equipment can occur. If the level is too low, reduction in efficiency of the treatment and recirculation function. Pressure can also build to dangerous levels. A drum level control system tightly controls the level whatever the disturbances, level change, increase/decrease of steam demand, feed water flow variations appears.

## **3.2 Boiler Drum Level Control**

Boiler drum level control is critical for the protection of plant and safety of equipment. The purpose of the drum level controller is to bring the drum level up to the given set point and

maintain the level at constant steam load. An intense decrease in this level may expose boiler tubes, allowing them to become overheated and damaged. An increase in this level may cause interference with the process of separating moisture from steam within the drum, thus the efficiency of the boiler reduces and carrying moisture into the turbine [11]. Typically, there are three strategies used to control drum level. With each successive strategy, a refinement of the previous control strategy has been taken place. For extent of the load change requirements, the control strategy depends on the measurement and control equipment.

The three main options available for drum level control are discussed below.

### **3.2.1 Single Element Drums Level Control**

The single element control is the simplest method for boiler drum level control system. It is least effective form of drum level control which requires a measurement of drum water level and feed water control valve. It is mainly recommended for boilers with modest change requirement and relatively constant feed water condition. The process variable coming from the drum level transmitter is compared to a set point and the difference is a deviation value. This signal is given to the controller which generates corrective action output. The output is then passed to the boiler feed water valve, which adjusts the level of feed water flow into the boiler drum.

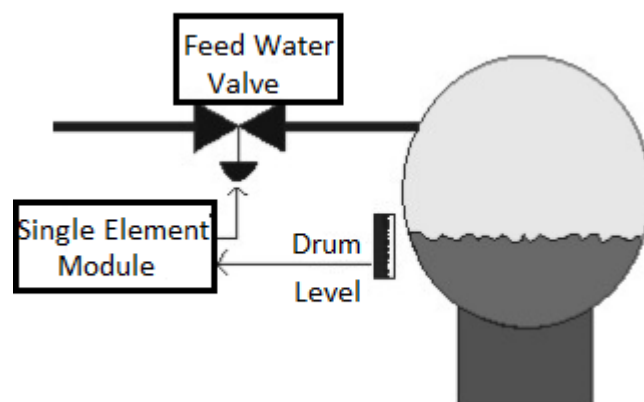


Figure 3.3 Single element boiler drum level control

### 3.2.2 Two-Element Drum Level Control

The two element drum level control system can be best applied to single element boiler drum level control system where feed water is at a constant pressure. It requires the measurement of drum level, load demand and feed water control valve. The load demand change is inferred from the steam flow rate measurement. Level of drum water is affected by the heating rate of the burner. The higher the heating rate, more water vapour bubbles are formed and causing the water volume to expand.

The two element boiler drum level control system has two variables, drum level and steam flow, to manipulate the feed water control valve. Steam flow load changes act as a feed forward controller to the feed water control valve. This feed forward controller provides an initial correction for the load changes. Imbalance between feed water mass flow and steam mass flow out into the drum is corrected by the level controller. This imbalance can arise from blow down variation due to change in the dissolved solids, variations in feed water supply pressure or leaks in steam. The feed water flow range and steam flow range are matched so that, a one pound change in steam flow results in a pound change in feed water flow.

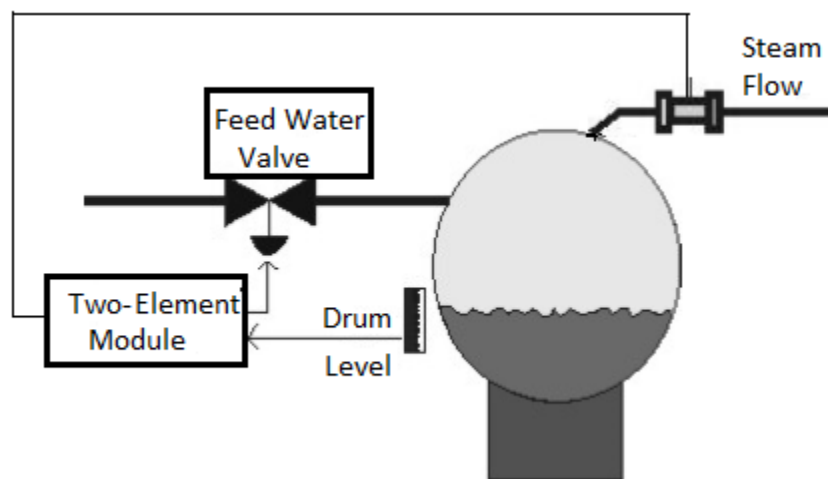


Figure 3.4 Two element boiler drum level control

Two element boiler drum level control system is adequate for a load changes of moderate speed and magnitude. It can be applied to any size of boiler. It has two drawbacks i.e. it cannot adjust for pressure or load disturbances in the feed water system and it cannot eliminate phasing interaction between the various portions of the process. If these disturbances are of prime concern, than three element boiler drum level control system can correct the drawbacks.

### 3.2.3 Three-Element Drum Level Control

This control system is ideally suited where a boiler plant consists of multiple boilers and multiple feed water pumps or feed water valve has variation in pressure or flow. It requires the measurement of drum level, steam flow rate, feed water flow rate and feed water control valve. By using cascade control mechanism level element act as a primary loop and flow element act as a secondary loop and steam flow element act as a feed forward controller. Level element and steam flow element mainly correct for unmeasured disturbances within the system such as boiler blow down. Feed water flow element responds rapidly to variations in feed water demand either from the feed water pressure and steam flow rate of feed forward signal.

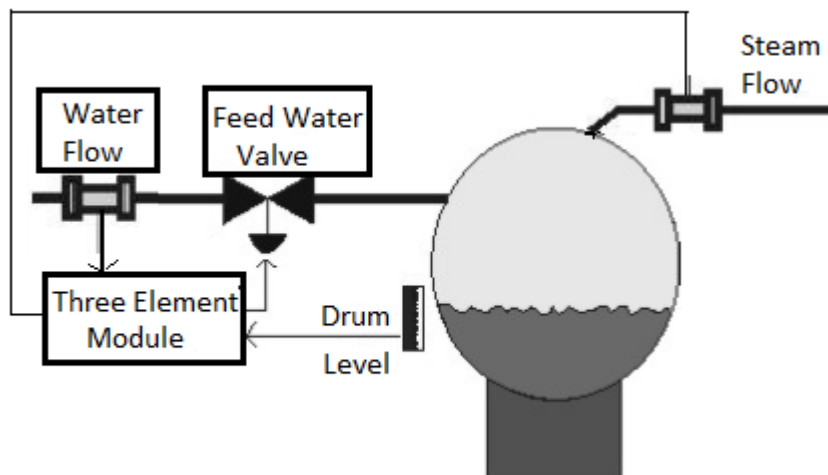


Figure 3.5 Three element boiler drum level control

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. This system can handle large and rapid load changes and feed water disturbances. It is ideal for plants with both batch and continuous process where uncertain steam demand changes are common.

### **3.3 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.

The drum level is derived from the following equation.

$$h = DP + H(\gamma_r - \gamma_s) \div (\gamma_w - \gamma_s) \quad (3.1)$$

Where:

$h$  = True drum level (Inches)

$DP$  = Measured DP head (Inches)

$H$  = Distance between taps (Inches)

$\gamma_s$  = Steam Specific Gravity (S.G.)

$\gamma_r$  = Reference leg (S.G.)

$\gamma_w$  = Drum Water (S.G.)

### 3.4 Simulation

The simulation results are shown here for different control strategies. The relationship between the feed water flow rate and drum level for the boiler process is taken from [12]. The process function, valve function and disturbance function is shown below.

$$G_p(s) = \frac{0.25(-s+1)}{s(2s+1)} \quad (3.2)$$

$$G_v(s) = \frac{1}{(0.15s+1)} \quad (3.3)$$

$$G_d(s) = \frac{-0.25(-s+1)}{s(2s+1)} \quad (3.4)$$

Where:

$G_p(s)$  = Process Function

$G_v(s)$  = Valve Function

$G_d(s)$  = Disturbance Function

From these parameters, the value of PID controller is calculated for the boiler through different control strategies. Three different controller i.e. feedback controller, feed forward controller and cascade controller has been applied in the system.

#### 3.4.1 Feedback Controller

In feedback control system, the variable being controlled is measured and compared with a given set point value. This difference between the actual and desired value is called the error. Feedback control reacts to the system and works to minimize this error. The block diagram of single element boiler drum level for feedback control system is shown in Fig. 3.6. To design the PID parameters of feedback controller, three different control methods are applied and correspondingly simulation results are shown.

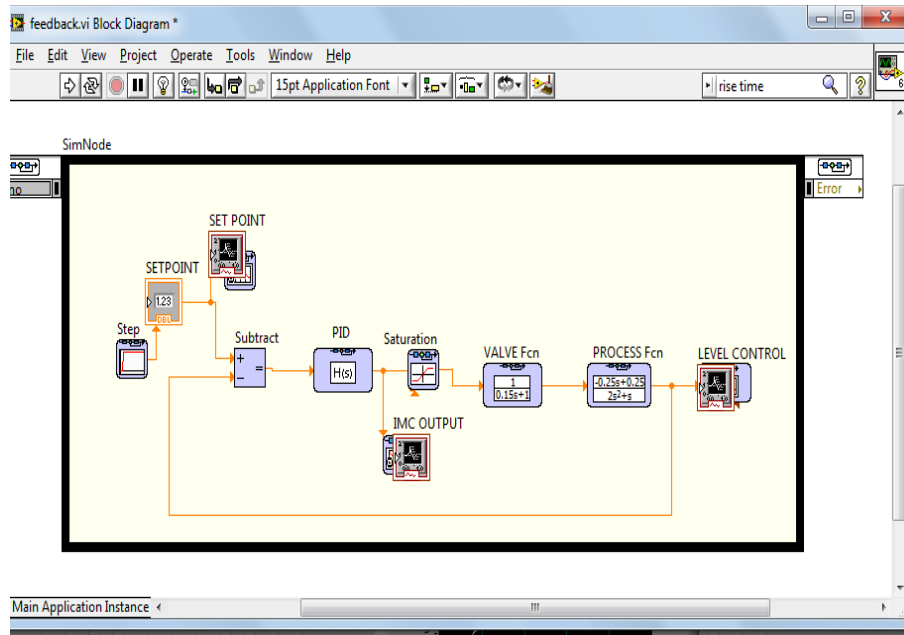


Figure 3.6 Single element boiler drum level for feedback control system

#### 3.4.1.1 Ziegler-Nichols Method

This is the simplest method to calculate the parameters of PID. Fig. 3.7 is the step input for the above simulation as shown in Fig. 3.6. It shows the step input response which is set point of the drum level of boiler.

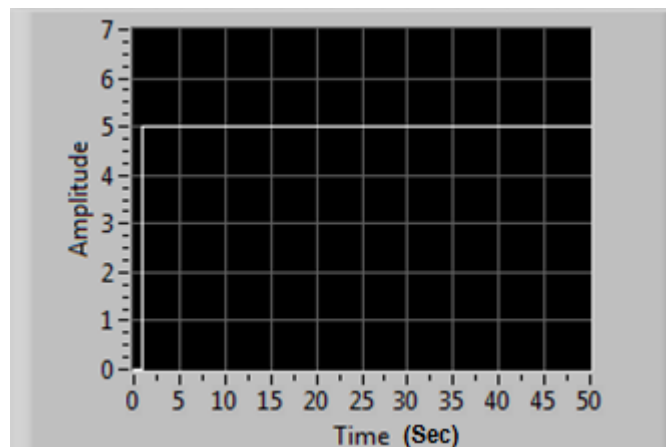


Figure 3.7 Step input response

By applying this method, the PID parameters obtained are

$$K_p = 2.1, K_i = 0.42, K_d = 2.625$$

Applying this PID parameter to the block diagram of boiler drum level control system, the response obtained is shown in Fig. 3.8. It shows the response of the PID controller output which reaches its set point after taking too long time. The response of the system is not stable. Hence, Tyreus-Luyben method is used for better response.

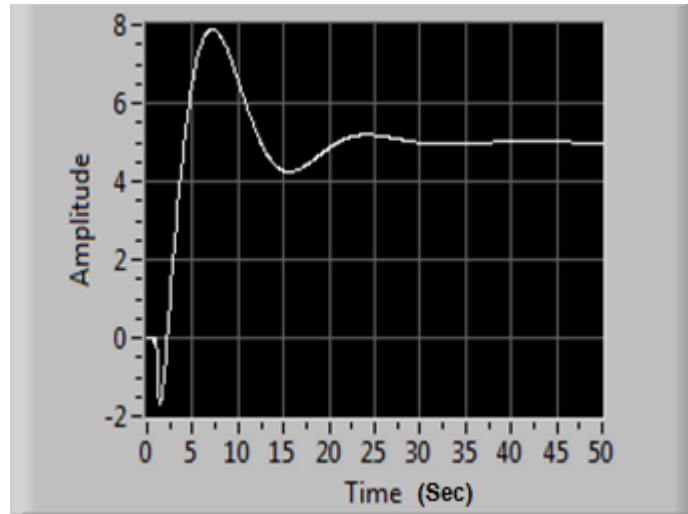


Figure 3.8 Ziegler Nichols PID controller response with step input

#### 3.4.1.2 Tyreus-Luyben Method

This is the another method to set the tuning values. By applying this method, PID parameters obtained are as follows

$$K_p = 1.59, K_i = 0.072, K_d = 2.52$$

Fig. 3.9 shows the output response of the system. The response of the PID controller is improved and the system is stable as its oscillatory effect is reduced but its settling time is large.

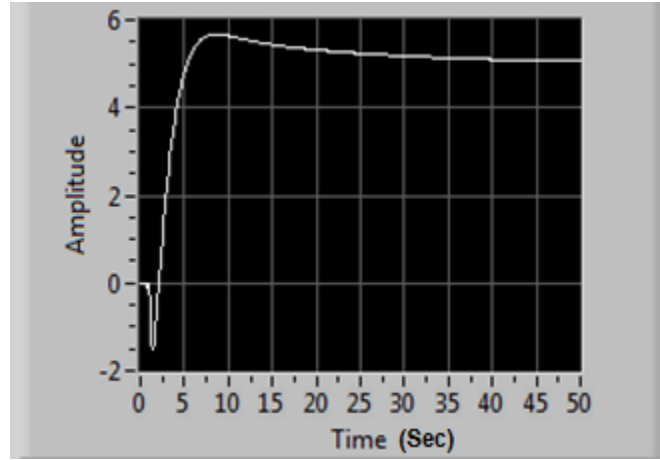


Figure 3.9 Tyreus-Luyben PID controller response with step input

### 3.4.1.3 Internal Model Control (IMC)

In this process, following process model is considered and correspondingly the controller output is calculated.

$$G_p(s) = \frac{0.25(-s+1)}{s(2s+1)(0.15s+1)} \quad (3.5)$$

$$Q(s) = \frac{4s(2s+1)(0.15s+1)}{(s+1)(\lambda s+1)^2} \quad (3.6)$$

$$G_c(s) = \frac{Q(s)}{1 - G_p(s) * Q(s)} \quad (3.7)$$

By putting the Eq. (3.5), Eq. (3.6) in Eq. (3.7), the desired value of controller is calculated, which depend on the filtering parameter  $\lambda$ .

$$G_c(s) = \frac{1.2s^3 + 8.6s^2 + 4s}{\lambda^2 s^2 + (2\lambda + \lambda^2)s + (2\lambda + 2)} \quad (3.8)$$

Putting  $\lambda = 1$

$$G_c(s) = \frac{1.2s^3 + 8.6s^2 + 4s}{s^2 + 3s + 4} \quad (3.9)$$

Now putting this value of  $G_c(s)$  to the controller and corresponding, the output response is shown in Fig. 3.10. The response of the system is stable and its settling time is low. Therefore, its response is fast so that the boiler level should reach its set point very quickly. The performance of the system in IMC is improved as compared to Ziegler-Nichols and Tyreus-Luyben methods. Hence, IMC based PID controller is applied to other processes.

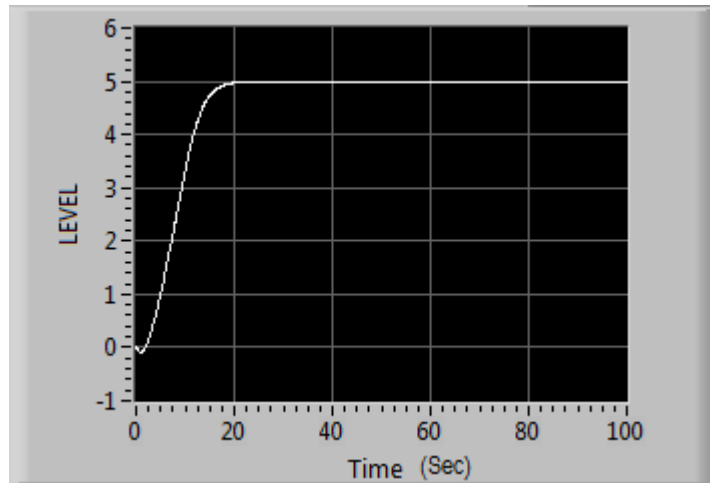


Figure 3.10 IMC based PID controller response with step input

### 3.4.2 Feedback and Feed Forward Controller

When steam disturbance is added in the system, than single feedback controller is not enough to control the whole process. So, a feed forward controller is added which removes this disturbances before it enter into the boiler plant. Feed-forward control avoids the slowness of feedback control system. Fig. 3.11 shows the block diagram of the feedback and feed forward controller of 2 element boiler drum level control. In this block diagram, the feed forward controller control the steam disturbances present in the boiler. To calculate the parameter of controller for steam disturbances, following calculation have been taken.

$$G_p(s) = \frac{0.25(-s+1)}{s(2s+1)(0.15s+1)} \quad (3.10)$$

$$G_d(s) = \frac{-0.25(-s+1)}{s(2s+1)} \quad (3.11)$$

$$G_{cf}(s) = -\frac{G_d(s)}{G_p(s)} \quad (3.12)$$

By putting the value of Eq. (3.10) and Eq. (3.11) in Eq. (3.12), the desired result is obtained.  $G_{cf}(s)$  acts as a feed forward controller for steam disturbance rejection.

$$G_{cf}(s) = \frac{0.15s+1}{s} \quad (3.13)$$

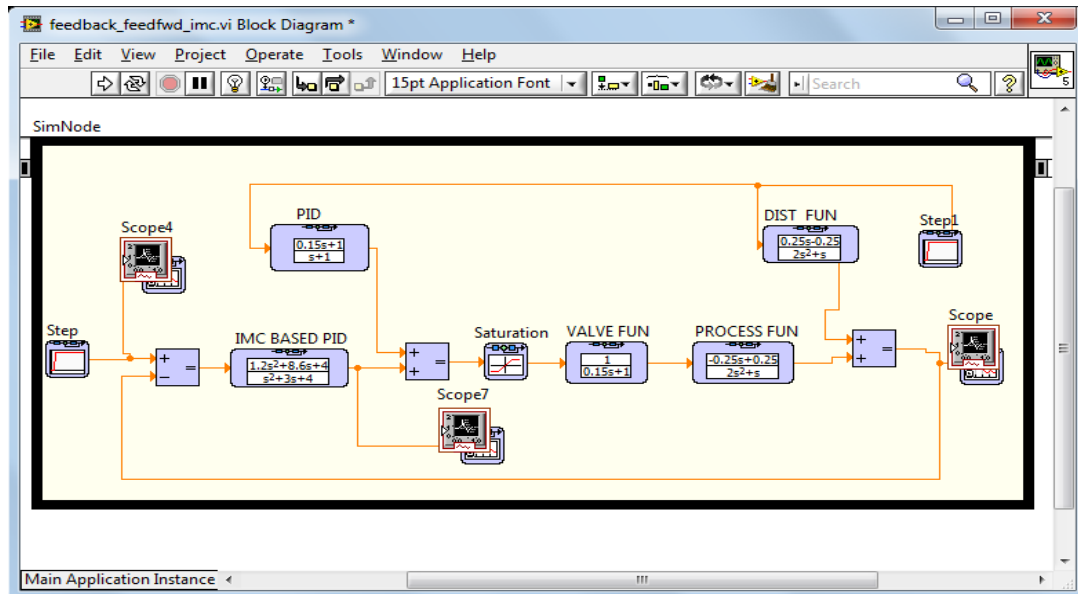


Figure 3.11 Block Diagram of Feedback and Feed Forward Controller.

Fig. 3.12 shows the output response of the controller. The output of the system removes all the disturbances and level of the boiler reaches its set point. To reduce the rise time of this system cascade controller is designed.

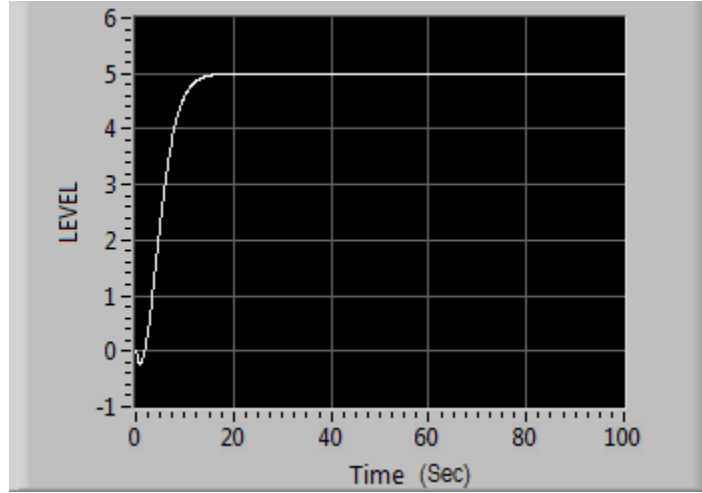


Figure 3.12 PID controller response with step input

### 3.4.3 Cascade Controller

To make the system fast, one more parameter is added here is flow of water. To control this parameter, cascade control system is designed. Cascade Control uses the output of the primary controller to manipulate the set point of the secondary controller as a final control element. Fig. 3.13 show the block diagram of cascade control for 3 element boiler drum level control system. Cascade control system is designed, in which level control acts as a primary controller and flow control acts as a secondary controller. PID control system is designed to reject this flow disturbance.

$$G_{cv}(s) = \frac{0.47s + 6.8}{s} \quad (3.14)$$

Where  $G_{cv}(s)$  is the flow controller of the secondary loop of cascade system.

The response of the system is stable and settling time is reduced as shown in Fig. 3.14. Cascade controller responses are very fast as compared to all earlier control strategies. IMC based PID response is better than Ziegler-Nichols and Tyreus-Luyben method.

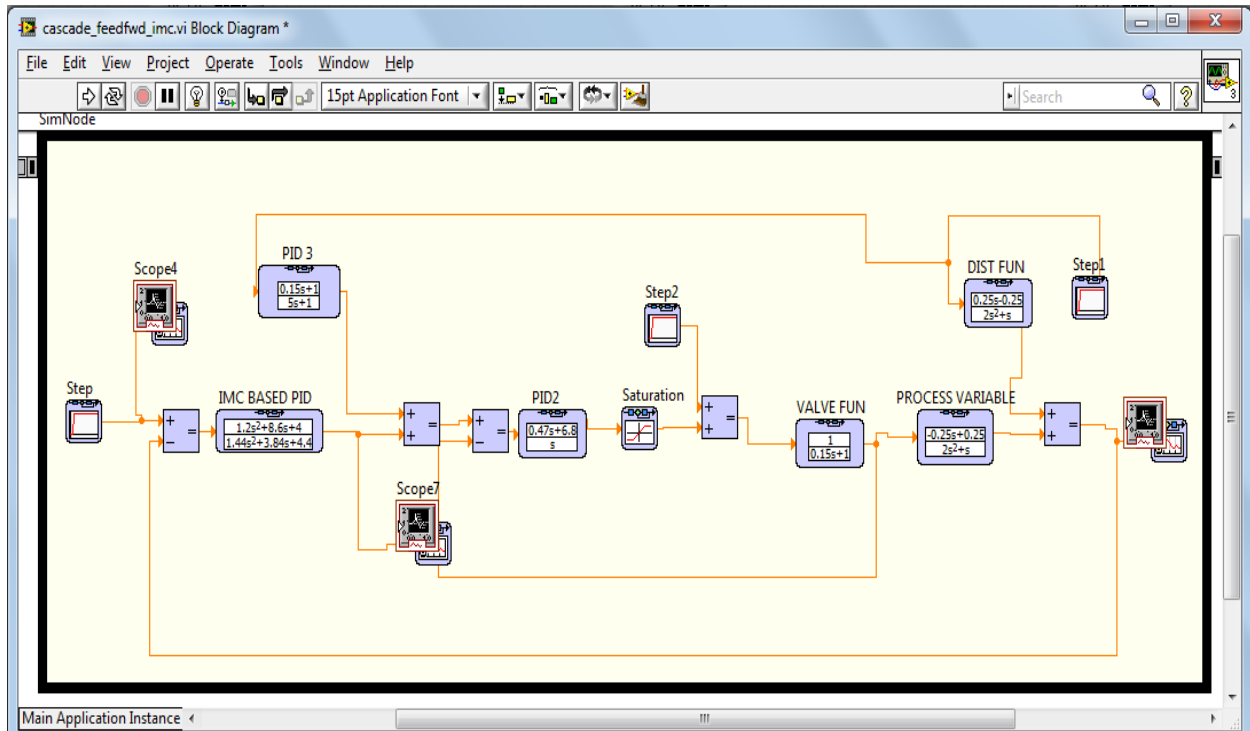


Figure 3.13 Block diagram of cascade control system

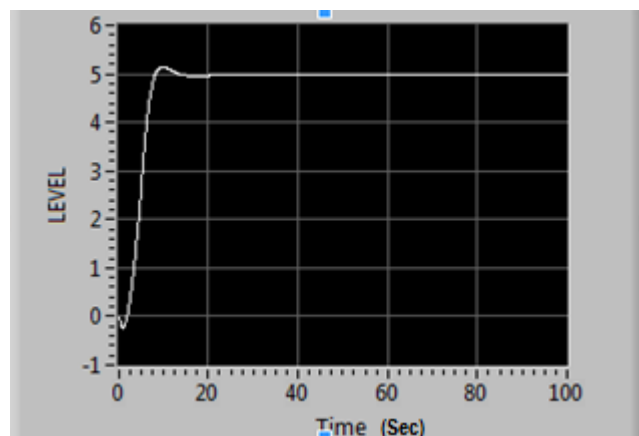


Figure 3.14 PID controller response with step input

### 3.4.4 Fuzzy Adaptive Control

In the Fig. 3.15, block diagram of the fuzzy adaptive PID controller is designed in the *Circuit Design and Simulation* toolkit in LabVIEW. Fuzzy controller works as primary controller and IMC controller works as secondary controller. Different fuzzy rules will be applied to obtain various responses.

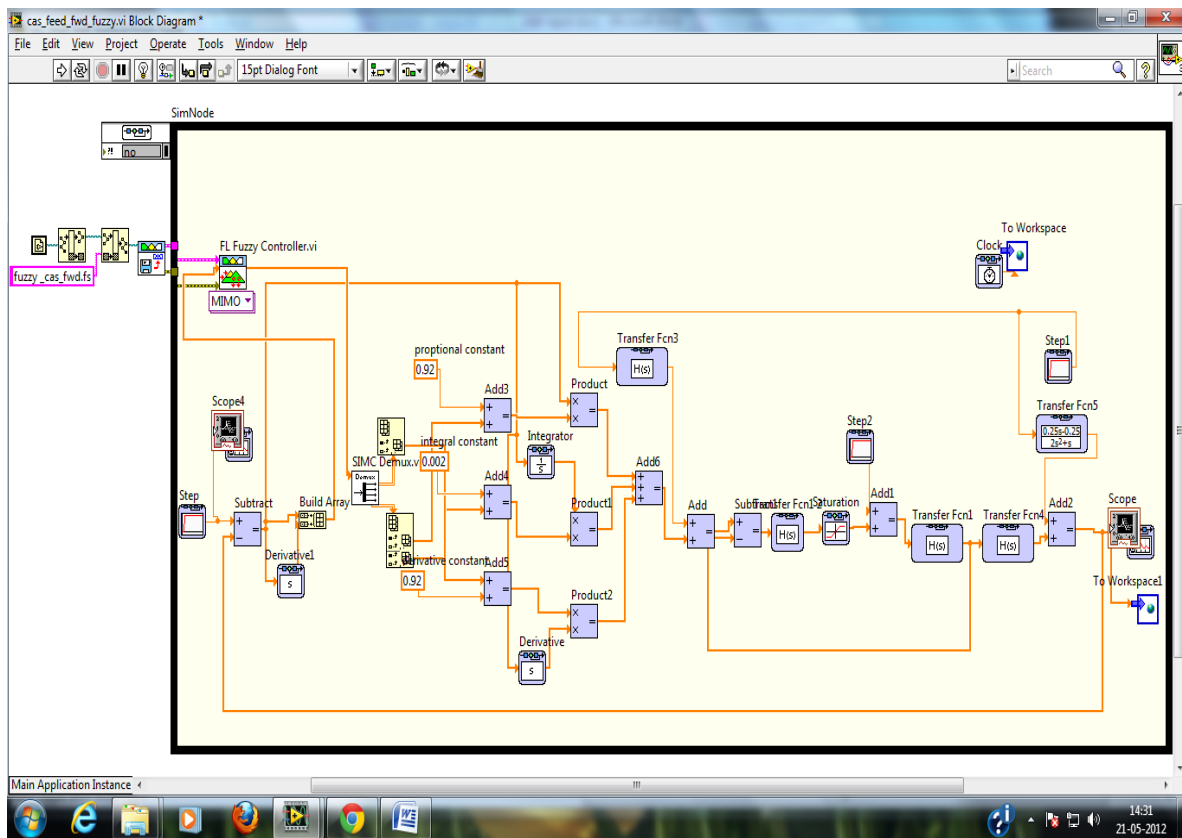


Figure 3.15 Block Diagram of Fuzzy Adaptive PID Controller

Fig.3.16 shows the membership function plots for the two input and three output variable level. The inputs are the error and the error rate. The outputs are the  $K_p$ ,  $K_i$  and  $K_d$  values. It has members as Negative Big (NB), Negative Medium (NM), Negative Small (NS), No Change (NC), Positive Small (PS), Positive Medium (PM) and Positive Big (PB). Range is taken from -1 to 1.

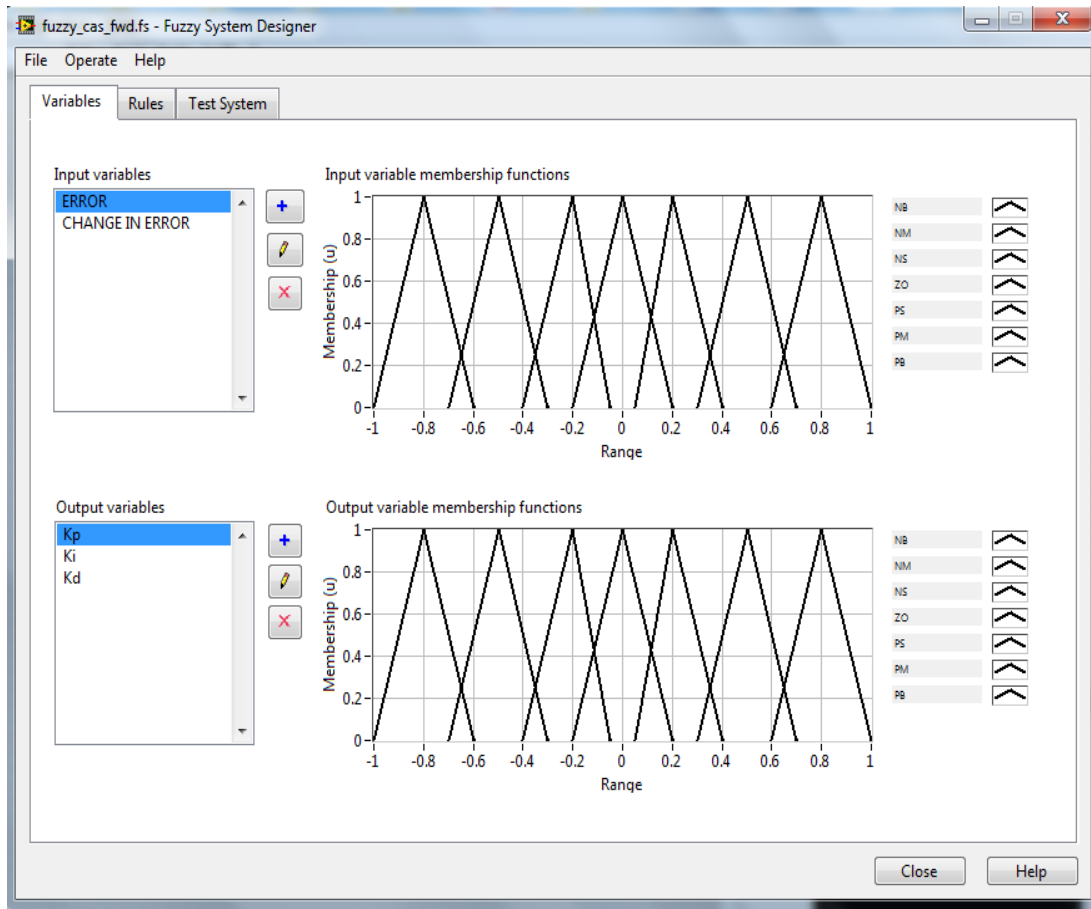


Figure 3.16 Input/Output Membership Function (Using Mamdani Method)

Fig. 3.17 shows the rule based of the fuzzy logic controller for the three element control system. It consist of forty nine rule based using If-and-then rules condition for each Kp, Ki and Kd values. Total of 147 rule base is designed for Fuzzy adaptive PID controller and that file is saved as fuzzy.fs file.

Fig. 3.18 shows the responses of the Fuzzy Adaptive PID controller for the step input. The performance of the system is very fast. Its rise time and settling time is very low. So, the response of the system is rapid. This controller performance is much better than the other PID controllers.

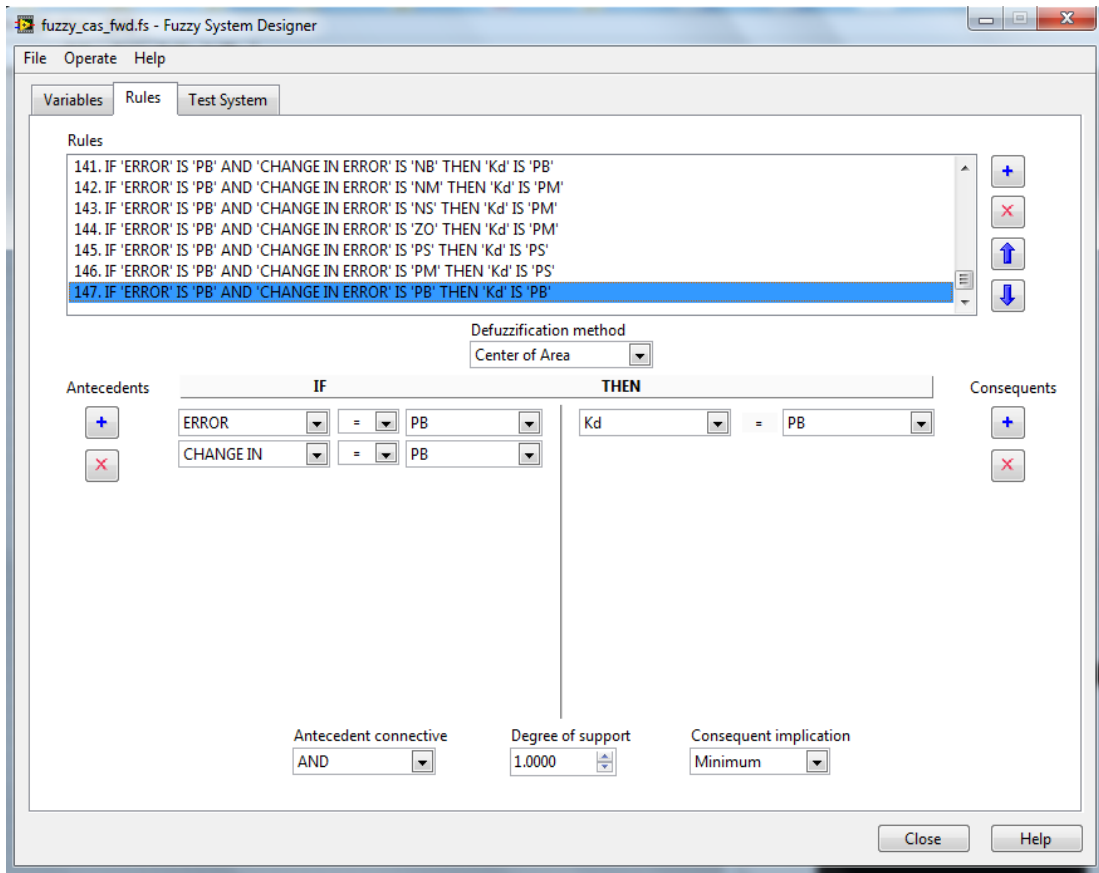


Figure 3.17 Fuzzy Rule Base

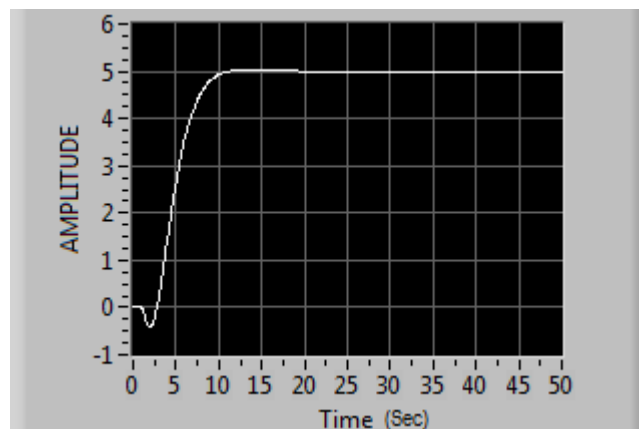


Figure 3.18 Fuzzy Adaptive PID Controller Response With Step Input

### 3.5 Result and Discussion

In this chapter, the simulation block diagram are implemented under LABVIEW environment using three different method of PID controller as Zeigler-Nichol Method, Tyreus-Luyben Method, Internal Model Control (IMC) and Fuzzy Adaptive PID control method. For the step input, the performance of the boiler for different controller is compared. The parameter considered are rise time, peak time, settling time and peak overshoot. Table 3.6 shows the comparison of the boiler performances through different controller.

Table 3.6 Comparison of the Boiler Performances through Different Controller

Controller Parameter	Ziegler Nichol	Tyreus- Luyben	IMC Feedback	IMC Feed Forward	IMC Cascade	Fuzzy Adaptive PID
Rise Time( $T_r$ )Sec	3	4	21	17	7	12
Peak Time( $T_p$ )Sec	6	7	-	-	11	-
Settling Time( $T_s$ )Sec	40	50	21	17	14	12
Peak Overshoot( $M_p$ )	60%	15%	-	-	5%	-

In this analysis, we have seen that more accurate result has been obtained using Fuzzy Adaptive PID controller. The response of the IMC based PID controller is very close to fuzzy Adaptive method. The use of IMC based PID controller improves the performance to great extent than both of these Zeigler-Nichol and Tyreus-Luyben PID tuning techniques. Settling time, rise time peak time and peak overshoot in case of Fuzzy Adaptive controller is less than other methods. When the plant response is changing with time, or there is uncertainty we prefer IMC method IMC based PID controller can adjust the control action before a change in the output set point actually occurs. Hence, from the above data, we conclude that the Fuzzy Adaptive PID method is better than other PID controller techniques.

# **CHAPTER 4**

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## **Data Logging and Supervisory Control**

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## DATA LOGGING AND SUPERVISORY CONTROL

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This chapter describes the concepts of data acquisition, data logging and supervisory control of boiler drum level control system. Simulation of data logging system is performed in the LabVIEW software. The generated result is logged into the database.

### 4.1 Introduction

Data is information, knowledge and conceptions obtained by observation, investigation, interpretation and visualization. Data are intangible and include numbers, words, symbols, concepts and oral verbalization [13]. Present world lives on data and advanced communication technologies. The word “Data” has now been upgraded into a term called “Statistical Data” which is defined as “Factual information such as measurements and statistics, especially information organized for analysis or used to reason or make decisions”.

Starting from the most simple day to day applications such as cell-phones, televisions and World Wide Web (www) to more complex and advanced operations like satellite & spacecraft communications, nuclear reactor control systems and automatic systems; there are statistical data spread all over the broad spectrum. It would have been impossible to acquire and control such a huge amount of statistical data without the modern computers and advanced digital signal processing methods. A major aspect of concern is the efficient and controlled management of this huge amount of data.

While there is a vast and diverse range of data all around, some of low importance & some highly critical, some secure and confidential & some un-secure, some raw & some processed; it becomes imperative that there should be some supervisory control system which would manage these widely varied data efficiently. The main objective of the supervisory control system would be to acquire data, extract only the necessary blocks of information from it, process it and derive

conclusion from it and store the data in some storage system for future reference. These ideas lead to Data-logging & Supervisory Control system [14].

## 4.2 Data Acquisition

Data acquisition is the process of sampling signals that measure real world physical condition and converting the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition system convert the analog waveforms into digital values for processing. Transducer is a device that converts a measurable physical quantity (temperature, strain, acceleration) to an electrical signal. Signal conditioning can include amplification, filtering, differential applications, isolation, simultaneous sample and hold (SS&H), current-to-voltage conversion, voltage-to-frequency conversion, linearization.

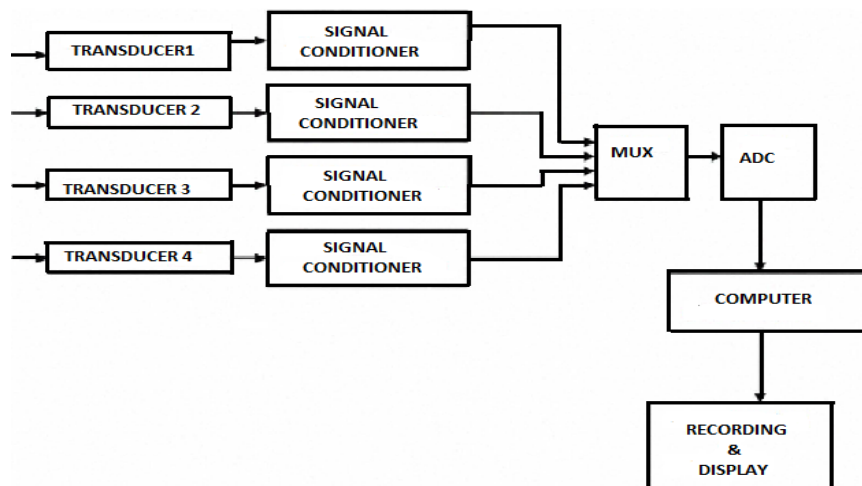


Figure 4.19 Schematic Diagram of Data Acquisition System

Fig. 4.19 shows the schematic diagram of data acquisition system. Sensor is used to sense the physical parameters from the physical world. The output of the sensor is provided to the signal conditioning element. The main purpose of signal conditioning element is to remove the noise

and amplify the signal. The output of the signal conditioning system is provided to Analog to Digital Converter (ADC). The ADC converts the analog signal to the equivalent digital data. The equivalent digital data is then fed to the computer, which acts both as a controller and display element [15].

### **4.3 Data Logging**

Data logging is the measurement and recording of parameter over a period of time. The parameter can be temperature, strain, pressure, voltage, current etc. Once data has been acquired, the process of storing this information for future usages and reference is called data logging. For example: weather profile of a region is monitored and stored over a long period of time. Later this information is used to predict the future weather in that region.

Real world data logging applications are more involved in some combination of online analysis, offline analysis, display, report generation, data sharing than just acquiring and recording signal. Due to the advancement of modern computers, new PC based data-logging systems has been evolved. These systems combine the data acquisition and storage capabilities of standalone data-loggers with the archiving, analysis, reporting and display capabilities of modern PCs.

### **4.4 Supervisory Control**

After data acquisition and data logging function are completed, supervisory control comes in to action. A supervisory control system is a system that constantly keeps watch on the on going process and handles the situation according to its importance. In supervisory control the computer which acts as a controller compares the signal coming from the process with the reference value or set point to calculate the error.

The controller give decision according to the error is called as control action. The decision or control action is implemented in the process using actuator and final control element. The output of the controller is given to the digital to analog converter, which is then conditioned according

to the process needs. The final signal is passed to the process and control action is implemented in the process through actuator and final control element.

## 4.5 Simulation

Three element boiler level control has been designed using the circuit design tool kit in LabVIEW. Fig.4.20 show the front panel diagram of PID controller of Three element boiler level control in which steam flow element acts as a feed forward controller, level element acts as a primary loop and flow element act as a secondary loop in the cascade controller [16].

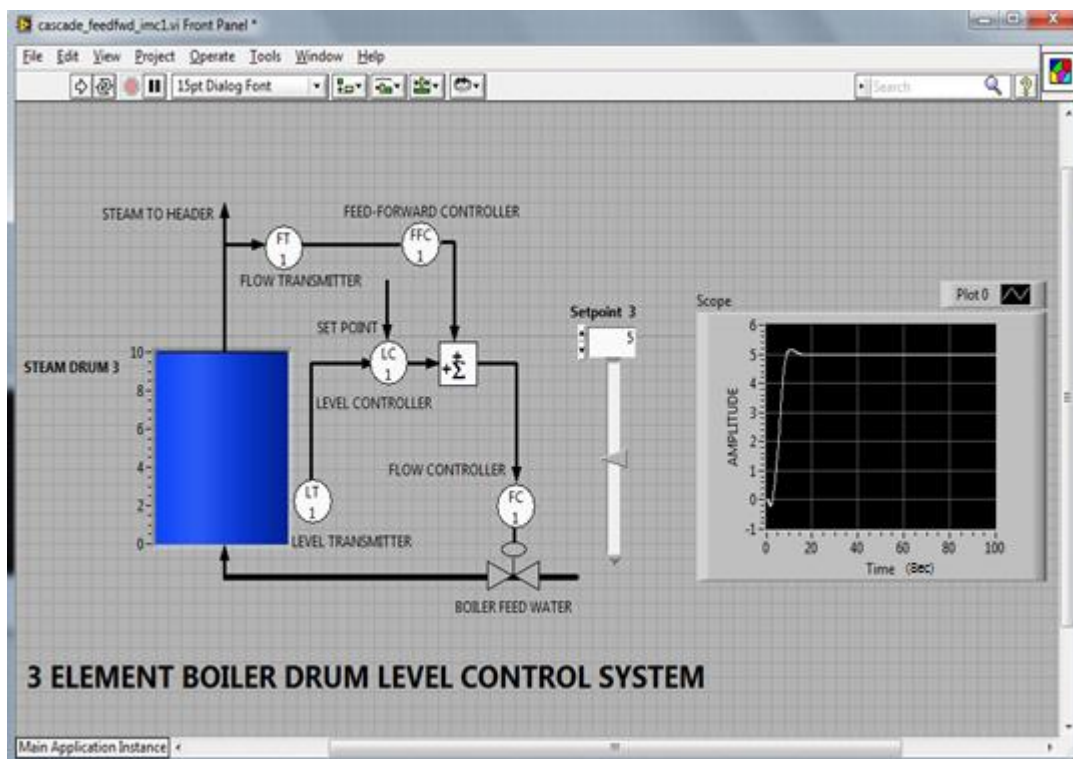


Figure 4.20 Front Panel Diagram of Three Element Boiler Level Control.

Level element and steam flow element mainly correct for unmeasured disturbances within the system such as boiler blow down. Feed water flow element responds rapidly to variations in feed water demand either from the steam flow rate feed forward signal and feed water pressure or flow fluctuations. The graph shows the unit step responses of the controller. Its rise time is very



with the real time plant. The front panel of the SCADA unit reports every change in level and temperature to the operator by showing the change in level and temperature in the front panel. The scaling factors of the boilers are indicated in the front panel.

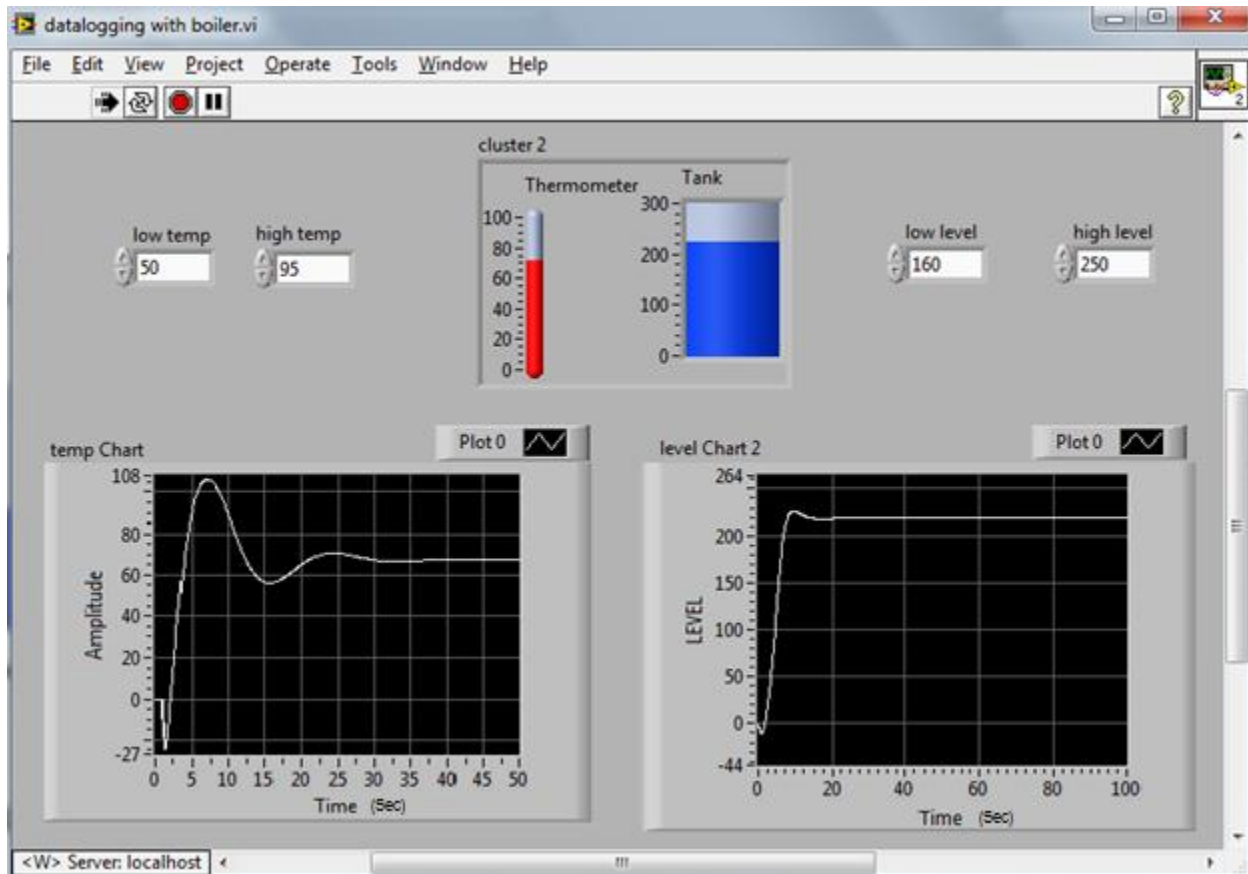


Figure 4.22 Web Based Front Panel of Data Logging System of Boiler.

In this data logging system, the real time trend of the process variable (steam temperature and drum level) are shown and all the data are stored in the database. The high and low units of steam temperature and drum level are also mentioned in the front panel.

Table 4.7 shows the database which is generated by the system. The database is generated in Microsoft excel sheet and stored in the computer. In this, the values of temperature and level are logged with appropriate date, time, the status of the level and temperature. The database appends all the data of the process variables as seen in Table 4.7. This database can be used to monitor

the process data in present as well as for future reference. This data can also be used for statistical process control applications.

Table 4.7 Database Stored In Excel File

<b>Time</b>	<b>Temp</b>	<b>Temp Status</b>	<b>Level</b>	<b>Level Status</b>
2:15:01	-21.42	Not Normal	5.534	Not normal
2:15:02	-7.88	Not Normal	7.264	Not normal
2:15:03	42.16	Not normal	40.723	Not normal
2:15:04	78.47	Normal	84.921	Not normal
2:15:05	93.15	Normal	94.433	Not normal
2:15:06	104.89	Not Normal	141.234	Not normal
2:15:07	108.11	Not normal	206.823	Normal
2:15:08	101.93	Not normal	210.324	Normal
2:15:09	93.55	Normal	222.276	Normal
2:15:10	84.11	Normal	225.284	Normal
2:15:11	75.06	Normal	223.522	Normal
2:15:12	67.36	Normal	221.322	Normal
2:15:13	41.83	Not Normal	215.678	Normal
2:15:14	58.45	Normal	218.988	Normal
2:15:15	60.75	Normal	218.68	Normal
2:15:16	57.91	Normal	217.678	Normal
2:15:17	59.94	Normal	217.824	Normal
2:15:18	60.75	Normal	217.867	Normal
2:15:19	64.46	Normal	218.284	Normal
2:15:20	66.62	Normal	218.504	Normal

# CHAPTER 5

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## Internet Based Control System

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# INTERNET BASED CONTROL SYSTEM

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This chapter presents the basic concept of internet based control system. Web based boiler drum level control system is developed by *Web Publishing* tool in LabVIEW. The concept of web services is explained. Architecture of Client/Server based on Internet is described. Simulation has been performed and HTML file is created.

## 5.1 Introduction

The Internet plays a significant role in real time industrial manufacturing, scheduling, monitoring and management. An extensive research work has led to the development of new technologies that uses the Internet for supervision and control of industrial processes. Internet-based control systems addresses the challenges that need to be overcome before the Internet can be beneficially used not only for monitoring of but also remote control industrial plants [18].

In the last decade, the most successful network developed has been the Internet that has proved a powerful tool for distributed collaborative work. The emerging Internet technologies offer unprecedented interconnection capability [19]. Internet-based control systems are characterized as globally remote monitoring by the Internet. In recent years, Internet-based control systems have gained considerable attention in science and engineering, since they provide a new and convenient unified framework for system control applications [20].

Modern day process plants, construction sites, agricultural industry, petroleum, power distribution network, wireless sensor network, refinery industry and every other industry where data is of prime importance use wireless data acquisition, data processing and data logging equipments [21]. Acquiring data from the field with the help of different sensors are always challenging. Essentially, Internet-based control systems have been developed by means of extending discrete control systems. The use of the Internet as a communication medium provides cost-effective, flexible and easy-to-access distributed control systems that are not limited to any geographical region.

## 5.2 Development of Internet Based Control System

The Internet is widely used for efficient and reliable dissemination of digital information. Thus, it is a natural choice for data communication tasks arising in remote monitoring and control of processes. In this work, we use the Internet as a channel to monitor and control boiler drum level control process. This methodology eliminates the need for the user to interact with the boiler process physically. Internet-based graphics tool, enable development of interactive graphical user interface (GUIs) for process monitoring and control [22].

### 5.2.1 Web Services

A Web service is a software system designed to support interoperable machine-to-machine interaction over a network. Web services provide a standard means of interoperating between different software applications, running on a variety of platforms and frameworks [23]. Web services enable the invocation of a method on a remote target using standard Web-based protocols. A client sends a request to a remote server, which processes the request and replies with a response, which is then interpreted and displayed by the client application. We rely on this communication method for everyday activities such as browsing the Web, checking e-mails and reading any article online.

All the components of a Web service are explained as follows.

- **Server**- An application responsible for parsing a request, executing the appropriate action or method and sending a response to the client.
- **Client** - An application that sends a request to the server and waits to receive a response back, which is then interpreted by the client.
- **Standard protocols** – Web based protocols such as HTTP route data over the physical networks from the client to the appropriate server method and then back to the client.
- **Network** – The physical layer, such as Ethernet or IEEE 802.11, over which data is transmitted.

### 5.2.2 Client/ Server Architecture

Client/Server architecture can be considered as a network environment that exchanges information between a server machine and a client machine where server has some resources that can be shared by different clients. Architecture of Client /Server based on internet is shown in Fig. 5.22. In order to develop the program on a server computer, LabVIEW Web Server (LWS) is used. Simulation of boiler drum level control model is created in LabVIEW by *Circuit Design and Simulation* toolkit. To access the boiler drum level control system through an internet, LWS program is used [24]. When all mentioned programs are appropriately operated on a server, a user friendly powerful program is obtained. On the computer of clients, only internet connection and internet explorer program are enough to monitor the boiler process. So, they do not need any additional programs.

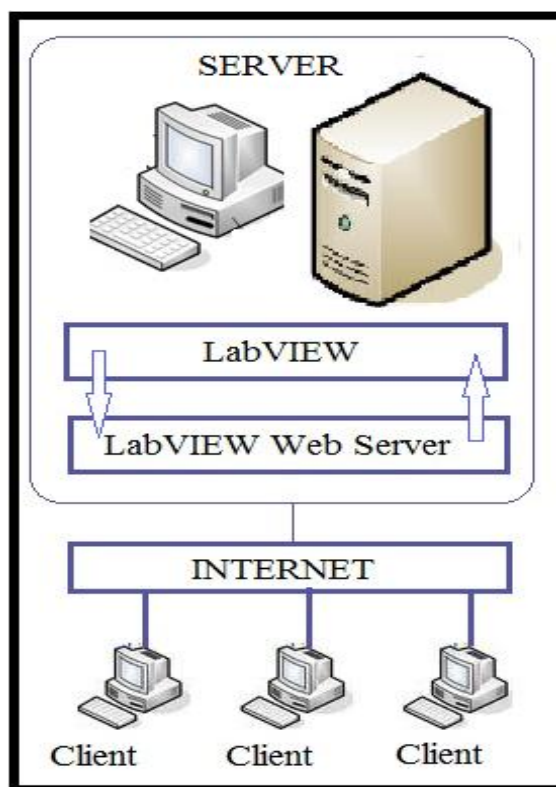


Figure 5.23 Architecture of Client/ Server based on Internet

### 5.2.3 Web Server Configuration

Web Server Configuration is used for deploying the LabVIEW VIs, for communication over a Web. To publish virtual instruments (VIs) on the Web, the Web Server must be enabled. The *Web Publishing* Tool is a LabVIEW built-in tool to publish the front panel of a VI as a HTML document to the web. To convert the LabVIEW program to HTML file following steps have been followed:

Step 1: “*Select VI and Viewing Options*”: This option publishes the VI, which must be in memory of the LabVIEW. The *Viewing Mode* can be changed between *Embedded*, *Snapshot and Monitor*. Embedded allows clients to view and control the front panel. Snapshot allows to display only a static image of the front panel. Monitor allows to display a snapshot with a configurable updating interval.

Step 2: “*Select HTML Output*” In this step, we can type the title (document title), a text before (header) the front panel and text after (footer) the front panel which are going to be displayed on the web page.

Step 3: “*Save the New Web Page*” In this step, the created HTML file of the VI is going to be saved to a directory with the selected filename and a URL will be created. After saving it, the VI is ready to be remote controlled from a client by typing this URL.

### 5.2.4 Advantages of Internet Based Control System

Some of the advantages of Internet based control system are discussed below.

- Global access to the monitoring and control functionality.
- Use of zero cost software (standard web browsers) on the client site to access information.
- Allowing collaboration among skilled plant managers situated in geographically diverse locations.
- Provides graphical user interface (GUI) to easily understand the control system.

## 5.3 Simulation

Internet Based process control system is designed in the *Web Publishing* tool in LabVIEW. Two simulation has been performed i.e. Internet based boiler drum level control system and Internet based data logging and supervisory control system

### 5.3.1 Internet Based Boiler Drum Level Control System

This work presents a general method to monitor the drum level control system through Internet. The user interface is shown in Fig. 5.24 through which, the user can select the boiler from three different boilers. By selecting 2<sup>nd</sup> tab, two element boiler drum level control system is selected as shown in Fig. 5.25. By selecting 3<sup>rd</sup> tab, three element boiler drum level control is selected as shown in Fig. 5.26. Now, the set point of the drum water level is selected through a slider tab and see the performance of the boiler in the graph (level vs time).

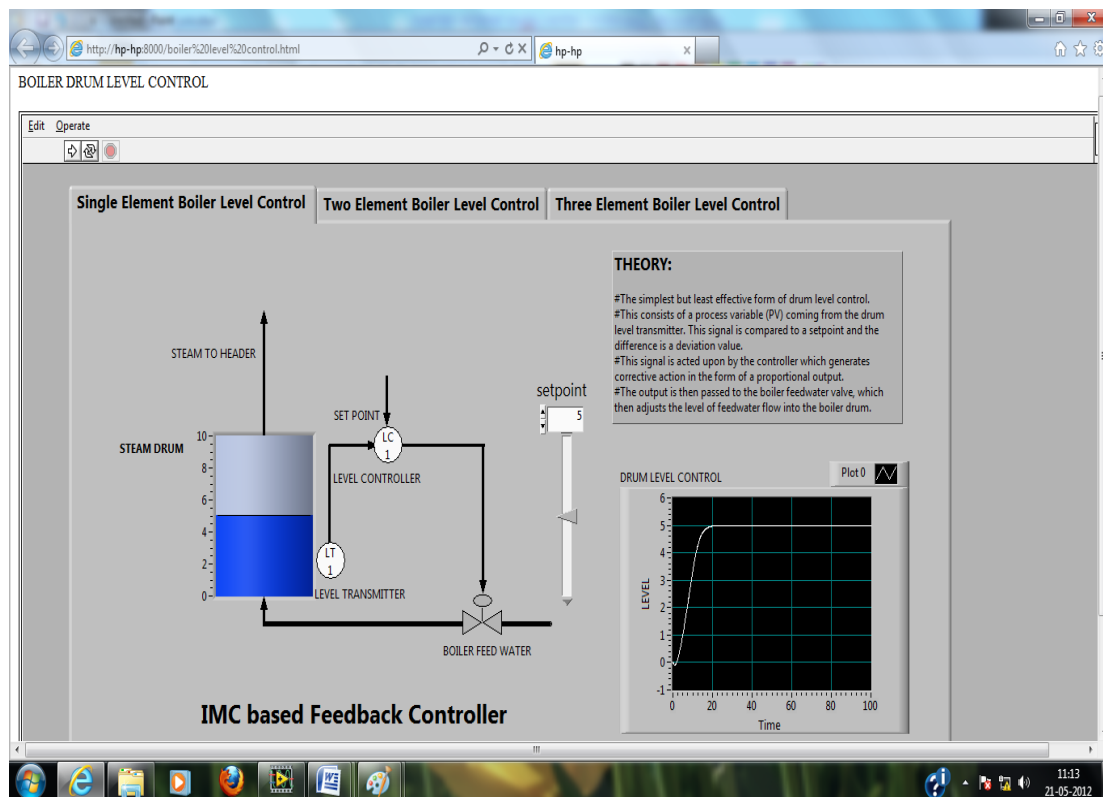


Figure 5.24 Internet Based Boiler Drum Level Control System (Single Element)

Through three different boilers, comparison between the performances of the boiler system is studied. Three element boiler level control response is very fast as compared to other two boilers.

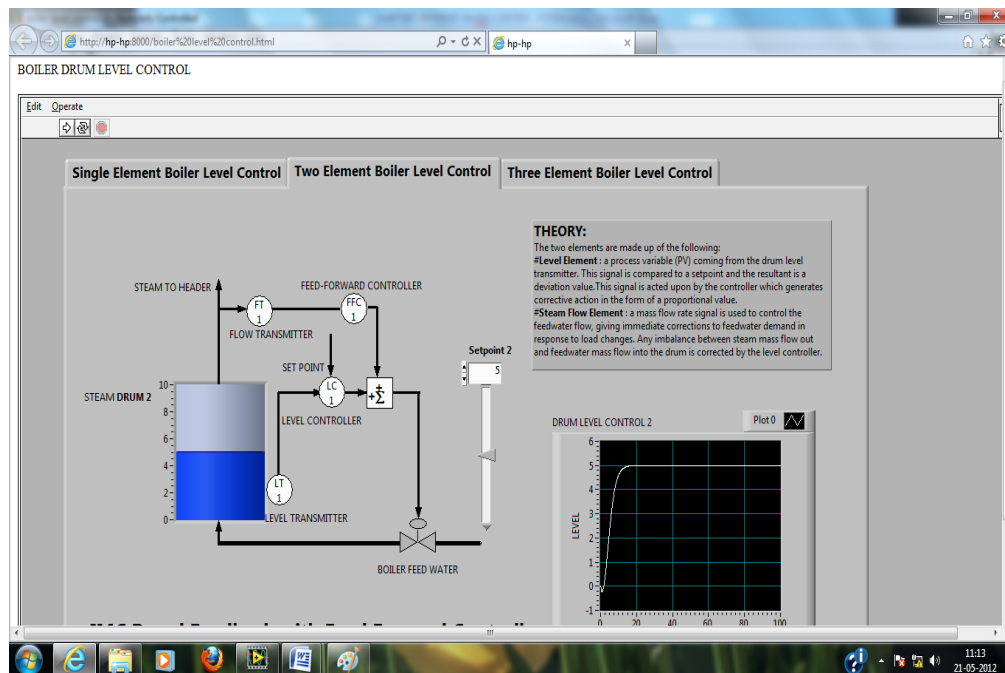


Figure 5.25 Internet Based Boiler Drum Level Control System (Two Element)

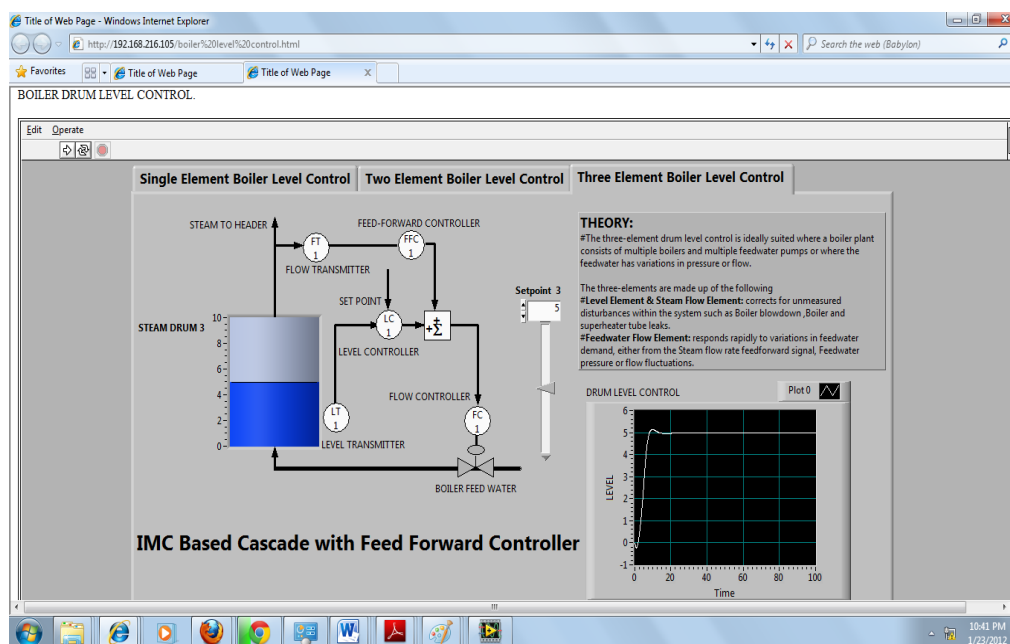


Figure 5.26 Internet Based Boiler Drum Level Control System (Three Element)

### 5.3.2 Internet Based Data Logging and Supervisory Control System

Internet based data logging and supervisory control program is simulated in the LabVIEW software. Fig. 5.27 shows the web page of the front panel of data logging system in HTML file. Only Internet Explorer browser is needed to open this HTML file. In this data logging system, the real time trend of the process variables (steam temperature and drum level) are shown and all the data are stored in the database. The high and low limits of steam temperature and drum level are also mentioned in the front panel. Through the internet, boiler process variable is monitored and data base is stored in text file. Internet based data logging and supervisory control system is designed to monitor the boiler system and store the database through internet from any where without any limitation of place and time.

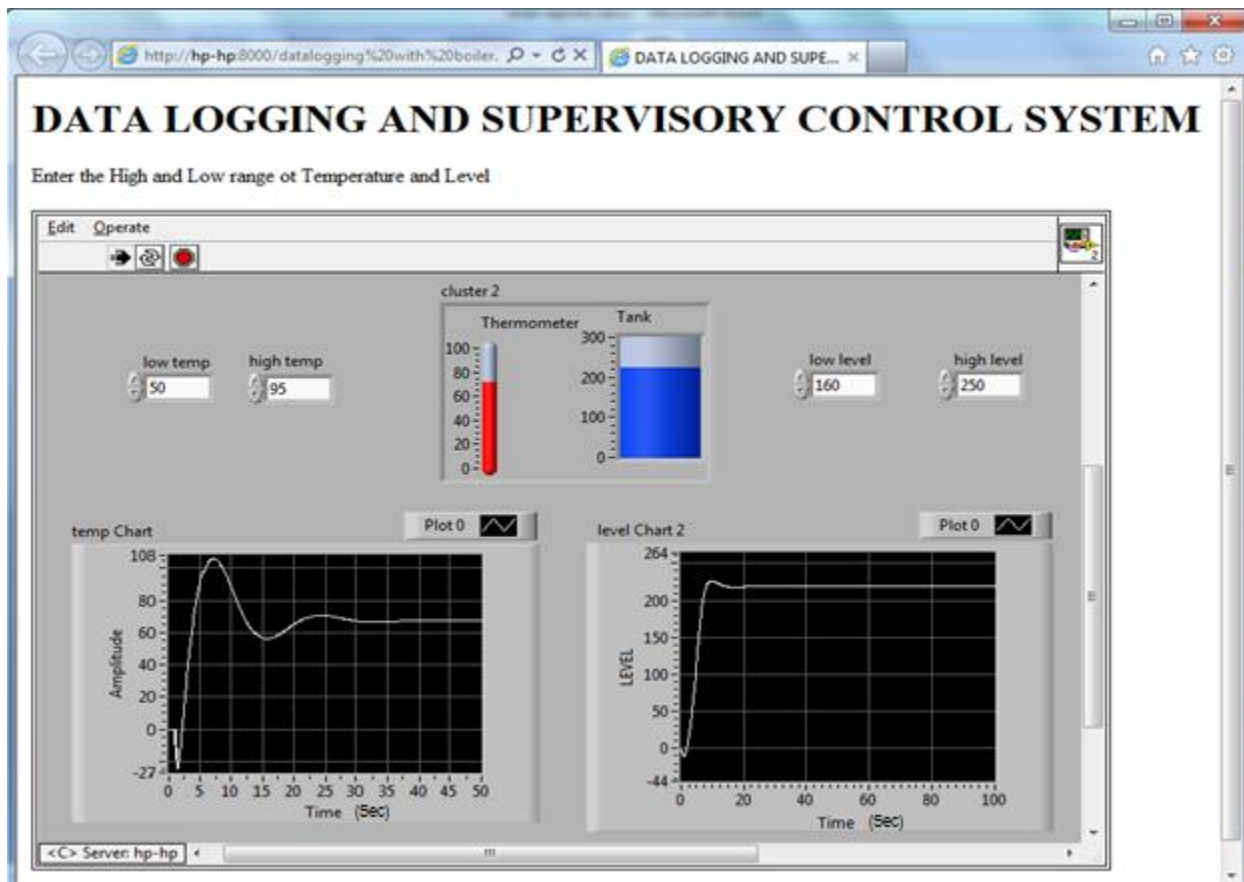


Figure 5.27 Web Based Front Panel Of Data Logging System Of Boiler.

## Chapter 6

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### **Conclusion**

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## CONCLUSION

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In this chapter the overall conclusion of the thesis is presented. Future scope of this work is also discussed.

### 6.1 Conclusion

In this thesis, first boiler drum level control system is designed with different controller strategies by using *Circuit Design and Simulation* tool in LabVIEW. Different PID control method is used i.e. Zeigler-Nichol Method, Tyreus-Luyben Method, Internal Model Control (IMC) and Fuzzy adaptive PID Control Method to design the controller for boiler. Comparison between the performances of the control strategies is studied and as a result the response of Fuzzy Adaptive PID control is more accurate than other controls methods. So, this controller is selected for the control system of boiler. The response of the IMC based PID controller is very close to fuzzy Adaptive method. The IMC based PID controller is used, when the plant response is changing with time, or there is uncertainty.

For the data logging and supervisory control of the boiler process, LabVIEW based data logging program is created. This program stored the process variables (Temperature and Level) data in Microsoft excel sheet with the proper indication of date and time status (Normal or Not Normal). Now, to view this boiler control system through remote places, Internet based boiler drum level control system is designed. To remotely monitor the boiler process, HTML file is created by using *Web Publishing* tool in LabVIEW. Now, this page can be accessed by Internet Explorer browser across any part of the world. Web based process control system is created by LabVIEW software. So, supervisory control of the whole process is possible just through Internet connection.

## **6.2 Future Work**

- Design and development of alarm system and to automatically send alarm notifying emails.
- For large amount of information, the speed of the next generation Internet might be sufficiently fast, to dramatically reduce transmission delay and data loss.
- Improvement is the security and reliability of the system.
- Design and development of more advanced controller for the boiler drum level control process.

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# Publications

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## Journal

R. Agrawal, U.C. Pati, “Internet Based Data Logging and Supervisory Control of Process Using LabVIEW”, *Journal of Instrument Society of India ISOI* (Communicated).

## Conferences

Roopal Agrawal, Umesh C. Pati, “Internet Based Boiler Drum Level Control System Using LabVIEW”, *International Conference on Advances in Computer, Electronics and Electrical Engineering (ICACEEE)*, Mumbai, Mar 2012.

Roopal Agrawal, Umesh C. Pati, “Design and Data Logging of Three Element Boiler Level Control Using LabVIEW”, *National Conference on Recent Advances in Chemical and Environmental Engineering (RACEE)*, Rourkela, Jan 2012.