Journal of Science and Technology
ISSN: 2456-5660 Volume 4, Issue 4, July-August 2019, PP 19-30
www.jst.org.in

Controlling Drum Level of a Boiler Using Fuzzy Logic Controller

[1]K V V Satya Ganesh, [2]A.Jawahar, [3]Ch.Vishnu Chakravarthy

[1]PG Student,. Department of Electrical and Electronics Engineering, Sanketika Institute of Technology and Management, Visakhapatnam, Andhra Pradesh, India
[2]Assistant Professor, Department of Electrical and Electronics Engineering, Sanketika Institute of Technology and Management, Visakhapatnam, Andhra Pradesh, India
[3]Head, Department of Electrical and Electronics Engineering, Sanketika Institute of Technology and Management, Visakhapatnam, Andhra Pradesh, India

Abstract – *Presently used modern techniques to control instead of the traditional control techniques for many industrial applications virtually or theoretically. In this paper, a Fuzzy logic has been applied to control the important variable of steam generator i.e., drum level. It was used simulation of Fuzzy system in MATLAB program. The results showed that the adoption of control technique that based on Fuzzy logic have a high response to indicate the control signals and thus can be depended as an active control system for selecting a right decisions compared with traditional systems. A very common control problem, and one used in many examples elsewhere, is that of controlling the level in a boiler drum. Many industrial plants have boilers for generating process steam, and of course boilers are central to thermal power generation. The boiler drum is where water and steam are separated. Controlling its level is critical – if the level becomes too low, the boiler can run dry resulting in mechanical damage of the drum and boiler piping. If the level becomes too high, water can be carried over into the steam pipe work, possibly damaging downstream equipment. Steam boiler provides appropriate quality and quantity of steam to the turbine for power generation. In drum type boiler, water and steam flow in the drum is controlled in such a way that the water level in the drum is maintained fairly at a preset value. While very low water level in the drum may lead to starvation and explosion of boiler, too high level may cause carryover of water particle and damages the superheaters. Therefore Drum level is an important parameter for safe operation of a boiler. Drum level in a drum type boiler is influenced by number of factors, such as sudden change in load demand and changed in heat input to the boiler etc. During Boiler Feed Pump (BFP) runback, the boiler steam generation is reduced through fuel cut off while steam out flow to the turbine is controlled by pressure controller. Under such circumstance, due to mismatch between steam out and feed water in, it becomes difficult in maintaining water level in the drum to its pre set value. This paper has suggested an innovative drum level control by adopting the Fuzzy controller. It module uniquely co-relates two independent time varying parameters namely steam flow and feed water flow in real time and accordingly apply correction of steam flow to match steam and water flow during BFP runback. Simulation result shows real time correction of steam flow maintains drum level within its safe operating limit during BFP runback. The innovative related rate module can be used as a control block in the future boiler controls for coordination between many parameters varying independently with respect to time. The adoption of fuzzy logic in control system gave the ability to take on decision for control signals with a high stability compared with traditional methods. The fuzzy system contributed in giving prophesies for station case to tell the operator what to do therefore enhancement the performance of station through to take a right decision to avoid stopping.*
Keywords: *BFP runback; Boiler simulation; Boiler*

1. Introduction

Much of the electricity used in our countries is produced by steam power stations. Thermal power stations contribute about 65% of the power supply in the world. However, electric energy is produce from some other sources such as hydropower, gas power, solar power, biogas power etc. Recently, the efficiency of this type of the stations is low despite efforts to develop energy converters. In order to get the demand of electrical power; the turbine requires an analogous amount of thermal power as well as this minimizing the losses leads to a decrease of pollutions. Now there is a modern technique called Fuzzy logic controller for improving the performance of boiler to increase the efficiency and productivity of power. Fuzzy logic represents soft computing method for solving problems where classical logic cannot provide satisfying results. Fuzzy logic is multi-value logic derived from theory of fuzzy sets proposed by Zadeh (1965). This kind of logic gained success because it makes use of the tolerance for imprecision and uncertainty to achieve tractability, robustness, and low cost solution. The fuzzy theory gives a mechanism linguistic constructs such as “many,” “medium,” “low,” “often,” “few.” In general, the fuzzy logic can be able to understand human reasoning. Fuzzy Logic Controller (FLC) has faster and smoother response than proportional integrated Derivative (PID) conventional systems and control complexity is less. In this paper Fuzzy interface system can use in Matlab program with cdl – file for controlling of boiler in thermal power plants provides a correct conditions to operator once happen any problem throughout the operation.

Drum type utility boilers with pulverized coal firing are provided with Boiler Feed Pumps (BFP) for supplying feed water to boiler. BFP runback occurs when one of the operating BFP gets tripped and the standby fails to start. Most of the time during BFP runback, drum level gets depleted beyond safe operating limit causing unit tripping. Simulation of the boiler feed water and steam generation system helps to understand the aforesaid system’s behaviour under both steady and transient operations. Numbers of models are suggested in literature to study the dynamic behaviour of drum type boiler. W.J. Peet et al have presented a mathematical model of a drum type steam generator where boiler is divided into lumped-parameter section. M.E. Flynn et al in their work have developed a model from first principles of conservation of mass end energy. While drum, down comer and riser have been lumped together, the super heater is modelled as a distributed parameter element. Usoro had developed a simulation model for all major equipments of a drum type boiler from mass, momentum and energy balance equations. The effect of burner tilt and availability of burner is modeled to introduce a coefficient of heat transfer as a function of burner tilt and burners in service. K.S. Bhambare et el have developed a model for coal fired natural circulation boiler. Both steady state and transient response can be studied through this model. Liu et al have developed a model for water level in the drum by mass and energy balance. Very few papers are available on Runback system. These papers have studied the performance of Runback system in general. In most of the cases the post outage effect is difficult to be studied just with discreet logic during Runback. This has been clearly indicated by the available papers. Li Bin et al have studied Runback of individual major auxiliaries through simulation. However the study has not covered Runback on Boiler Feed Pump (BFP) outages. Present work has simulated the transient behaviour of steam and feed water model and thereby has developed an innovative module on the Fuzzy logic controller and compared with principle of related rate variation, for managing the drum level during BFP runback. Simulation is performed for both the steady state and transient conditions using SIMULINK. Results show that the new control concept can manage drum level within its safe operating limit during BFP runback. First principle of mass, momentum and energy balance is used for developing models on ‘Steam generation in water wall’, ‘BFP and feed water flow’ and ‘Drum’.

II. Modeling Of Water Wall

The down comer water temperature is the same as that of drum water temperature with negligible heat loss. Mass conservation in the down comer can be expressed as

$$\dot{m}_{dci} - \dot{m}_{dco} = V_{dc} \frac{d\rho_{dc}}{dt}$$

Mass balance and momentum balance equations are used for both riser and down comer modelling. While developing Models in this section, heat resistance of the metal wall is neglected. The equation developed from momentum balance can be expressed as

$$P_{drs} - P_{dco} = K_{fdc} \frac{\dot{m}_{dc}^2}{\rho_{dc}} - l_{dc}\rho_{dc} g \cdot$$

$$P_{dco} - P_{wwo} = K_{fww} \frac{\dot{m}_{ww}^2}{\rho_{ww}} - l_{ww}\rho_{ww} g$$

Pressure difference between water wall outlet and down comer inlet can be expressed as

$$P_{drs} - P_{wwo} = (K_{fdc} \frac{\dot{m}_{dc}^2}{\rho_{dc}} - K_{fww} \frac{\dot{m}_{ww}^2}{\rho_{ww}}) - g(l_{ww}\rho_{ww} + l_{dc}\rho_{dc})$$

Considering circulation ratio 1:6 at rated drum pressure, the velocity of steam water mixture through the water wall down comer circuit comes out to be 8.4 meter/sec. Circulation ratio in the tube side affects the convective heat transfer coefficient. Considering circulation ratio as fairly constant during Runback, a single value heat transfer coefficient is evaluated and used in the present work. The convective heat transfer to saturated water is expressed as

$$Q_{ww} = h_{ww} A_{ww} \Delta T$$

where

$$\Delta T = (T_{mww} - T_w)$$

A zonal approach in the present work is adopted for water wall heat transfer modelling. The water wall is divided in 20sections of equal length and individual heat exchange for each section is evaluated separately. Assuming each section is in isothermal state, the heat flow for section 1 can be expressed as

$$Q_1 = h_{ww} A_n (T_{mww} - T_w) \quad = \sigma A_n \varepsilon_{fur} (T_{g1}^4 - T_{mww}^4)$$

Where T_{g1} is section 1 flue gas temperature which can be expressed as a

$$T_{g1} = \frac{\dot{m}_{air} C_{air} (T_{aph} - T_a) + \dot{m}_{fuel} C_{fuel} (T_{fuel} - T_a) + \dot{m}_{fuel} H_{fuel}}{\dot{m}_g C_g} + T_a$$

Similarly flue gas temperature at section 2 can be expressed as

$$T_{g2} = \frac{\dot{m}_g C_g T_{g1} - Q_1}{\dot{m}_g C_g}$$

Computing $Q_1, Q_2, Q_3 \ \ldots\ldots$ at all the sections,

Steam produced in the water wall =

$$\frac{\sum Q}{Latent\ heat\ (eva)\ at\ drum\ press}$$

Iii. Modeling of BFP and Feed Water Flow

The pump performance characteristics play an important role in providing a constitutive relationship between the flow rate and pressure head developed, which in turn is used for flow computation. The main boiler feed pump acts in series with the booster pump. The equation for the pump is developed through momentum balance. The head developed by pump in terms of flow is expressed by

$$\Delta H = K_1 \frac{W_p^2}{\rho_p} + K_2 N_p W_p + K_3 \rho_p N_p^2 \cdot$$

Computing the head requirement to deliver water at drum pressure and at required feed flow is expressed by

$$\Delta H = P_{dr} + K_f W_p^2$$

The feed water flow is determined through these two equations while the coefficients f K K , K & K 1, 2 3 are determined from characteristics curve supplied by the manufacturer. From above two equations after rearranging, the flow is computed as

$$W_p = \frac{-K_2 N_p \pm \sqrt{\{(K_2 N_p)^2 - 4(\frac{K_1}{\rho_p} - K_f) * (K_3 \rho_p N_p^2 - \rho_{dr})\}}}{2 * (\frac{K_1}{\rho_p} - K_f)}$$

Assuming system resistance fairly constant over the narrow range of operation at nearly full load, the relation between discharge and speed is derived and is expressed as

$$W_p = 0.24 N_p^3 - 4.924 N_p^2 + 341.31 N_p - 7860$$

where Np is the speed of feed pump in rps and discharge in Kg/sec.
The speed-time response characteristic of BFP is computed through experimental data collection during Runback and is expressed as 4th order polynomials

$$N_p = 2*10^{-6}t^4 - 0.0002t^3 + 0.0115t^2 - 0.0427t + 63.955$$

IV. Modeling of Drum

Water in the drum exists in two phases both in saturated condition. During Runback, drum pressure remains fairly constant, and therefore it can be assumed that both phases are in thermodynamic equilibrium condition. Mass balance in the drum can be expressed as

$$\dot{m}_{wo} + \dot{m}_{eo} - \dot{m}_{dc} - \dot{m}_s = \frac{d}{dt}(\rho_s V_s + \rho_w V_w),$$

The energy conservation in the drum can be expressed as

$$\frac{d}{dt}[\rho_s V_s h_s + \rho_w V_w h_w) = \dot{m}_{wo}h_{wo} + \dot{m}_{eo}h_{eo} - \dot{m}_{dc}h_w - \dot{m}_s h_s$$

Where mwois the steam water mixture flow rate through water wall, meo denotes the flow rate through economizer, mdc is the flow rate at the down comer and ms is the flow rate of steam at the outlet of the drum. Total volume of the drum (V) is the sum of the steam volume (Vs) and water volume (Vw). Transient equation for the drum water volume can be written as

$$\frac{dV_w}{dt} = \frac{\dot{m}_{wo} + \dot{m}_{eo} - \dot{m}_{dc} - \dot{m}_s - [(V - V_w)\frac{d\rho_s}{dp} + V_w \frac{d\rho_w}{dp}]\frac{dP}{dt}}{\rho_w - \rho_s}$$

The State variables are drum pressure (P) and water volume (w V). Thermodynamic constitutive relations used in the model are given in equation. For practical purpose narrow zone of steam table is used.

$$V_w = (-)10^{-19}P^2 + 5*10^{-6}P + 0.009$$

$$\rho_s = 0.0068P^2 - 1.0478P + 100.5$$

From drum geometry the drum level can be evaluated as

$$Y = 0.096V_w^2 + 47.88V_w - 520.5$$

V. RESULT AND DISCUSSION

5.1. Simulation of drum level control the subsystems are connected using SIMULINK to develop model of drum level control for a 200 MW unit. Inputs for drum system model are constructional design parameter, steam & water mixture output from water wall model and feed water flow from BFP model. Output is the drum level.

The simulation model thus developed is given in figure1.The model was simulated using Matlab SIMULINK. Differential equations describing the drum, down comer and riser were solved using ODE solver 45 with variable time step.

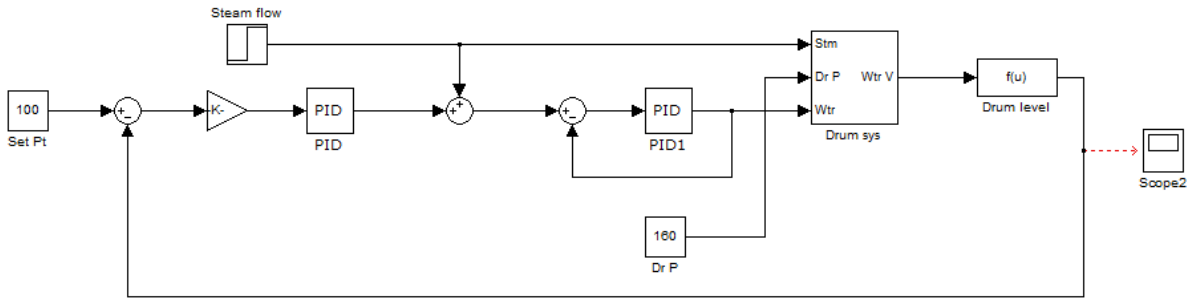


Fig1. Boiler drum level SIMULINK model

The model was tested with step command raising the steam flow by 10 %.
Figure 2 shows the response of drum level to a step increase in steam flow from 167 Kg/sec to183 Kg/sec at a drum pressure P= 160 Kg/Cm2. It is observed that initially drum water level swells and then came down to normal level.

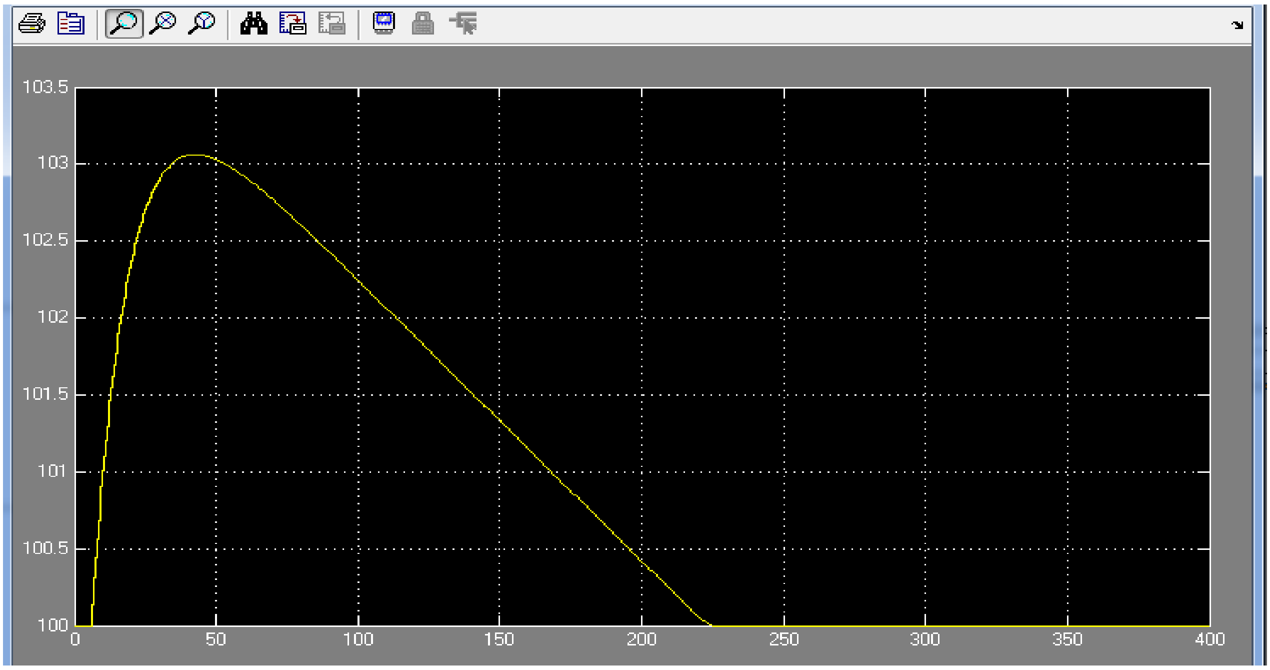
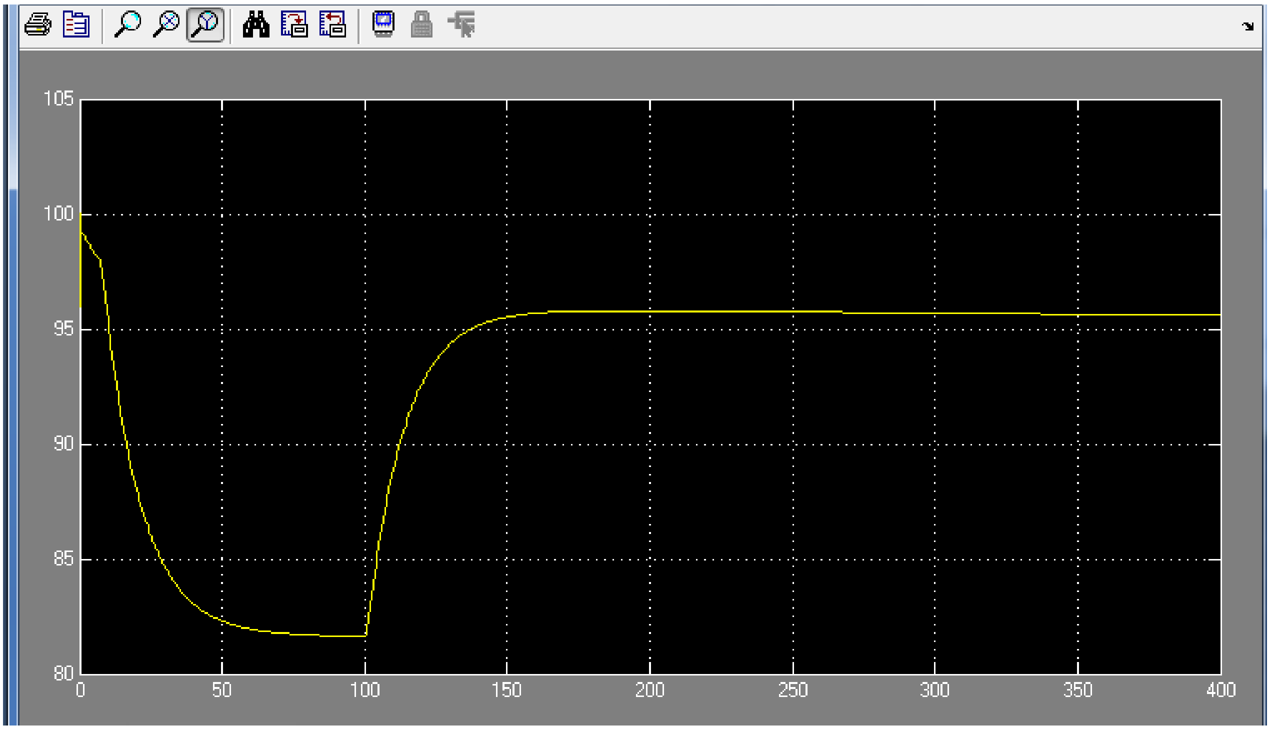


Fig. 2 Effect of 10 % increase in steam flow

Figure 3 shows that during BFP run back drum level comedown to very low level and can cause tripping of the unit. Real time coordination between feed water flow and steam flow during runback can manage the drum level much better way. Related rate control concept is introduced in the runback simulation model for real time coordination between steam and feed water flow.



X-Axis: Time in seconds
Y-Axis: Drum level in mm

Fig 3. Drum level variation during BFP runback

5.2 Related rate control concept

The concepts apply the principle of computing the rate of change of two independent time variant variables and use the output for controlling one variable. Implicit differentiation with respect to time is applied determining the rate of change. Applying this principle difference between the rate of change of feed-water flow and rate of change of steam flow during runback is evaluated. Integrating the solution variable over the time period of runback gives the net variation with respect to time. This signal with a gain function has been used to modulate the steam outflow to the turbine. A modified runback model developed in SIMULINK by introducing the related rate module. The simulation block thus modified with related rate module is given in fig 4.

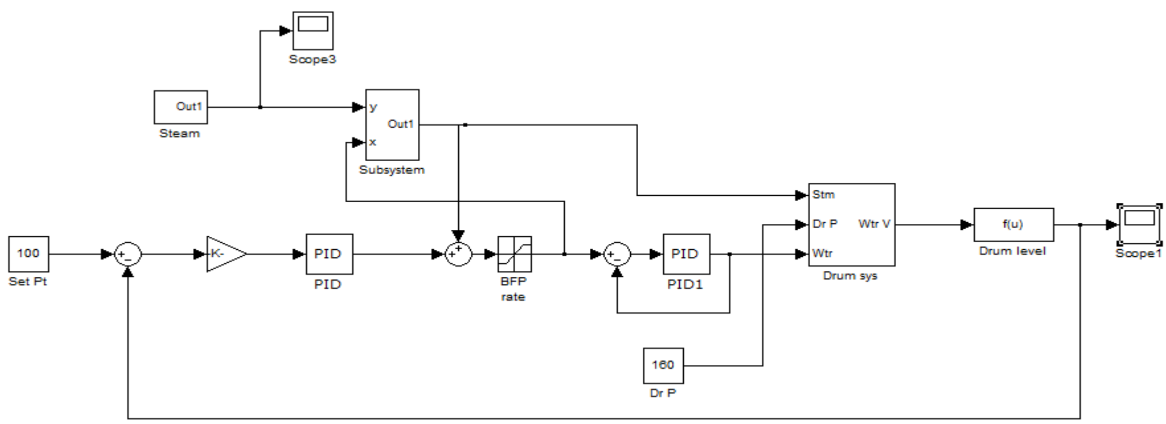


Fig 4. Modified BFP runback SIMULINK model

Computation of the related rate command is done in steps as shown in figure 5 in the flow chart. Initialization of the computation starts with input from feed water and steam flow equations. Numerical differentiation and integration method are used to solve the flow equations, setting derivative of states equal to zero for the given operating condition defined by BFP runback conditions. Command for steam flow by related rate module is superimposed on the steam flow demand generated by turbine follow mode operating command. The steady state plant data are collected for a coal fired drum type thermal power plant. The plant has a control system developed by Simens. Few operating parameter like steam generation in the water wall, feed flow, steam out flow etc. have been recorded through the instrumentation provided with the plant. Designed error in the measurement is ±1%. Table 1 shows the data recorded for the given boiler and those obtained from the simulation. A good correlation is found between the running parameters of the boiler and simulation result.

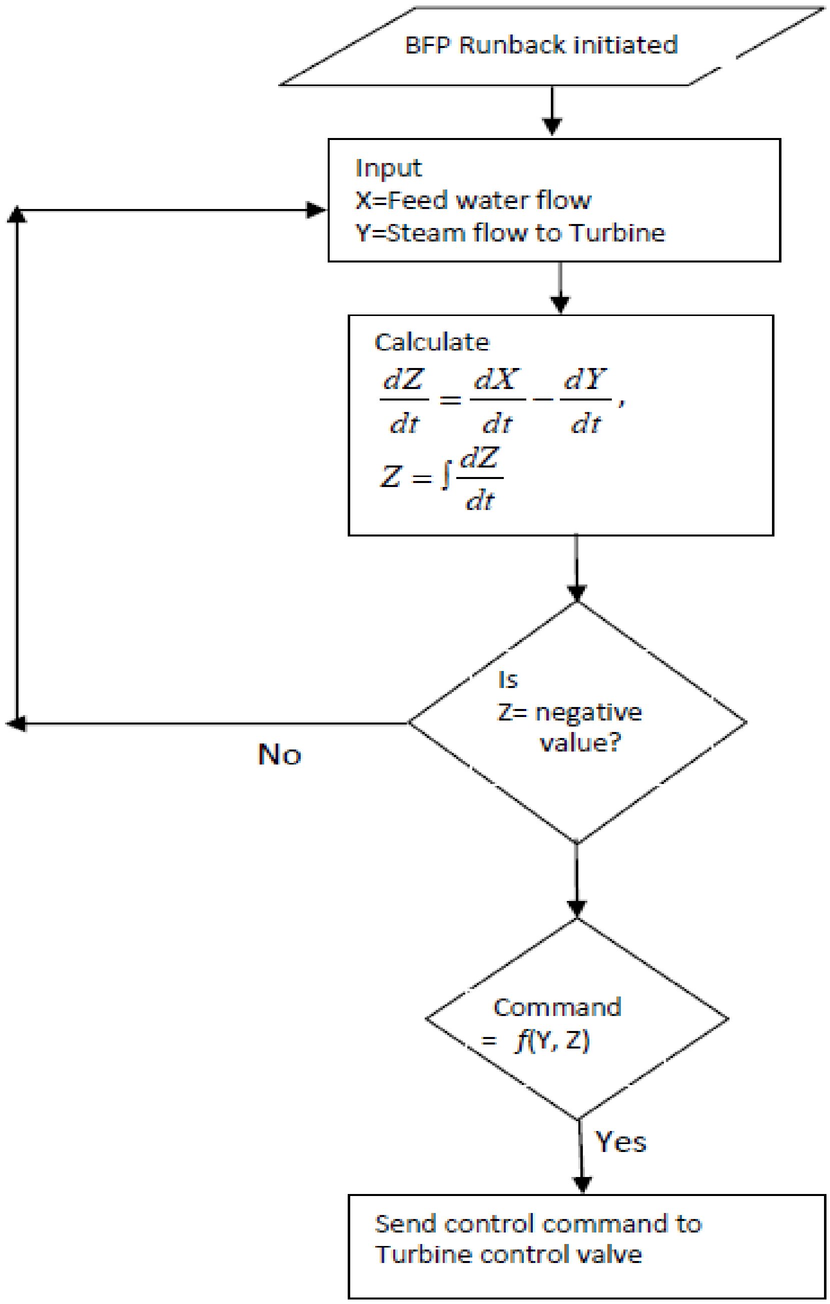


Fig 5.Computation scheme for related rate command

5.3 Boiler Drum level control with Fuzzy Logic Controller:Figure 6 shows Simulation of drum level control the subsystems are connected using SIMULINK to develop model of drum level control using Fuzzy controller**.**

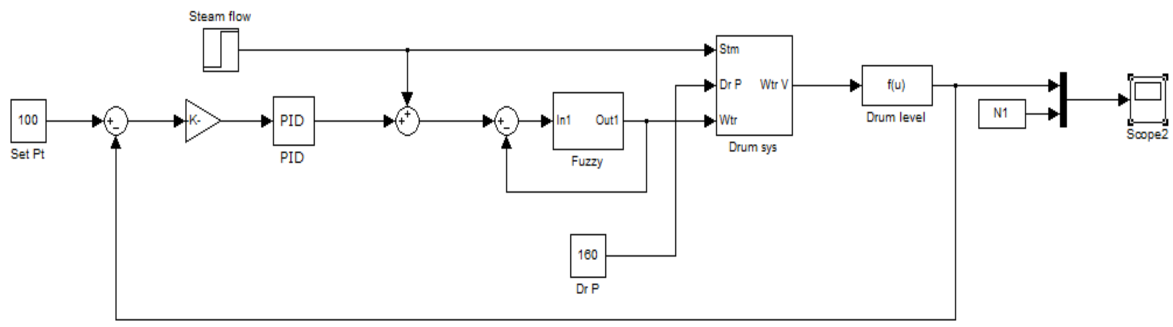
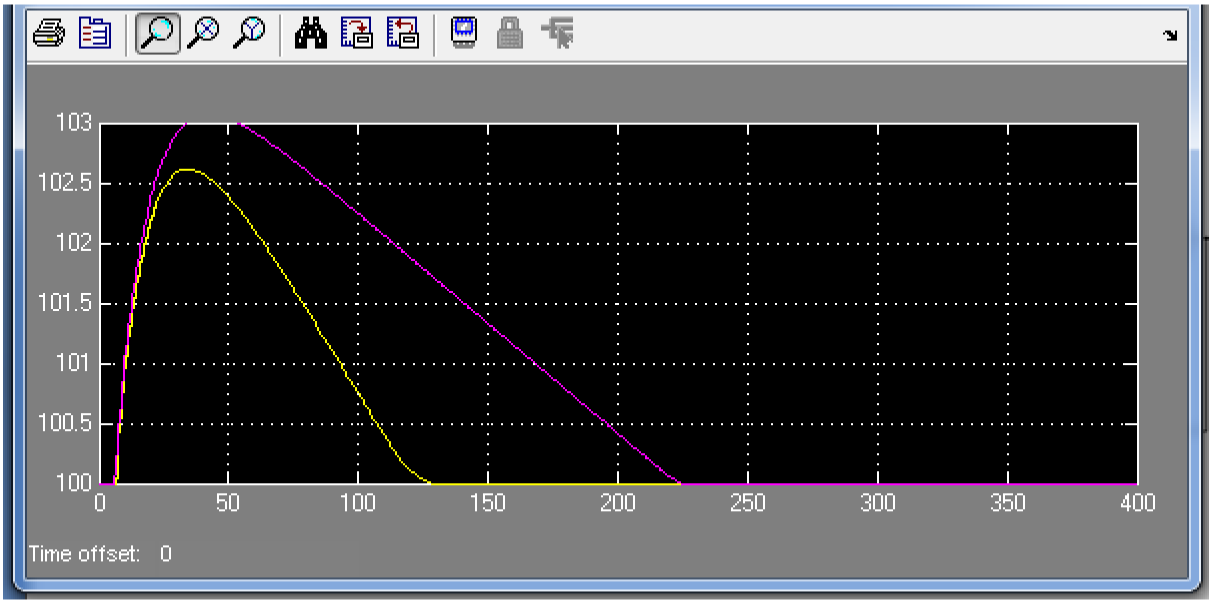


Fig6. Boiler drum level SIMULINK FUZZY model



X-Axis: Time in seconds
Y-Axis: Drum level in mm

Fig7 Graph between time and Drum level in mm

Fig7 shows the simulation result of drum level variation with related rate module and FUZZY logic.

5.4 Boiler Drum level control during runback with Fuzzy Logic Controller:

Figure 8 shows Simulation of drum level control the subsystems are connected using SIMULINK to develop model of drum level control using Fuzzy controller during runback.

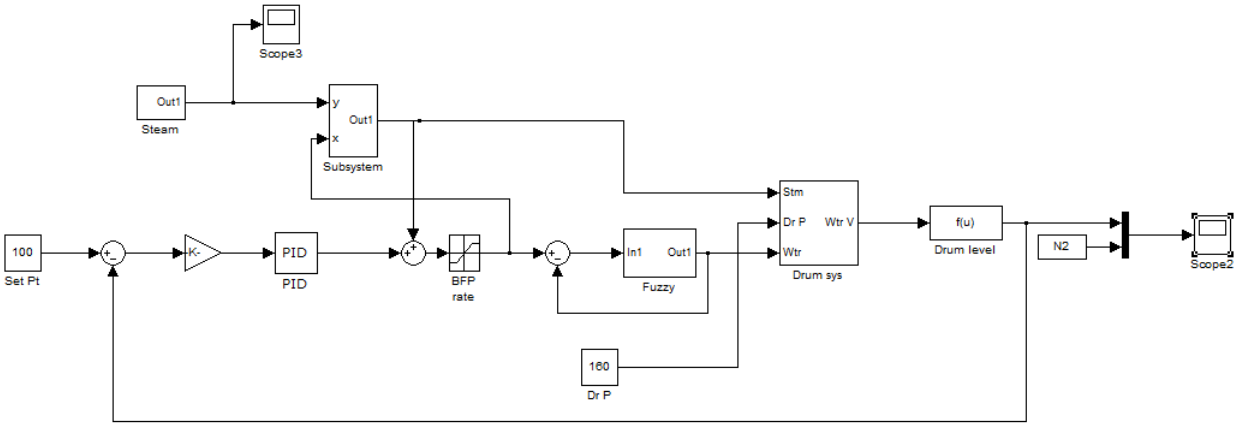
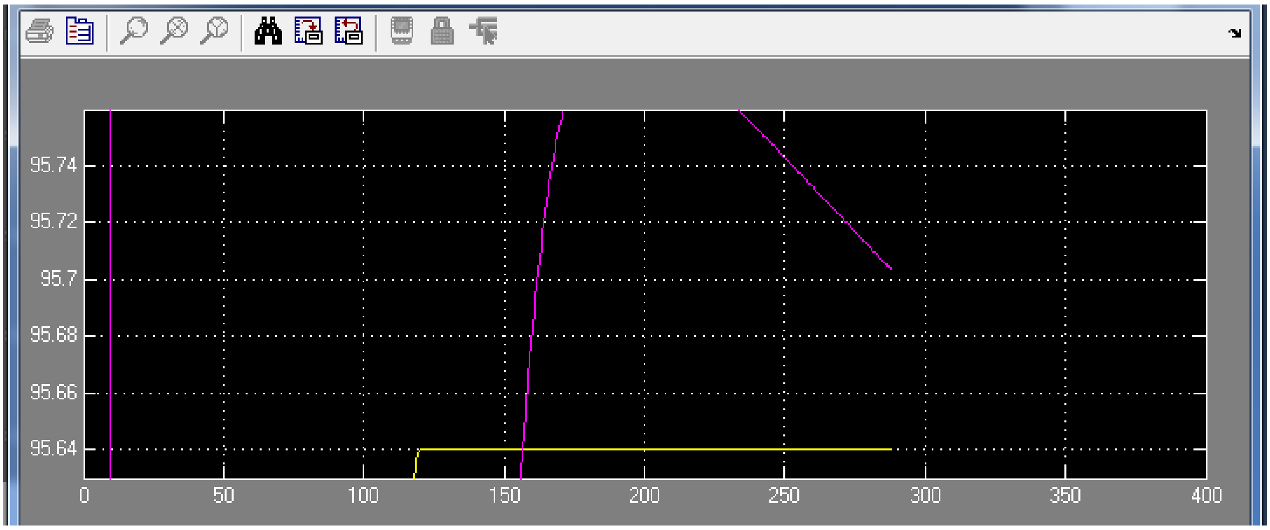


Fig 8. BFP runback SIMULINK FUZZY model

Figure 9 shows the simulation result of drum level variation with related rate module and FUZZY logic during runback. Depletion in boiler drum level during BFP runback could be arrested successfully.



X-Axis: Time in seconds
Y-Axis: Drum level in mm

Fig 9 Variation of drum level during BFP runback with FUZZY and related run rate

Introduction of Fuzzy logic in the run back simulation model has fine tuned the steam flow to the turbine under turbine follow mode.

VI. Conclusion

The present work for fuzzy simulation gave the following conclusions:

1. The results showed that the adoption of control technique that based on Fuzzy logic have a high response to indicate the control signals and thus can be depended as an active control system for selecting a right decisions compared with traditional systems.
2. The adoption of fuzzy logic in control system gave the ability to take on decision for control signals with a high stability compared with traditional methods.

3. The fuzzy system contributed in giving prophesies for station case to tell the operator what to do therefore enhancement the performance of station through to take a right decision to avoid stopping.
4. It gave the ability to take on decision for control signals with a high stability compared with traditional methods.

Present work has developed an innovative model referred as related rate module for controlling drum level during BFP It is observed that during BFP runback, drum level depletes faster because feed water flow is limited by the capacity of BFP and therefore coordination between steamflow and feed water flow gets disturbed. This is why drum level controller working on feed forward signal from steam flow is not able to control drum level during BFP runback.

Nomenclature

A	= area (m^2)
am	= volumetric quality (m^3/m^3)
C	= Specific heat (J/Kg)
d	= diameter (m)
g	= gravitational acceleration (m/sec^2)
h	= specific enthalpy (J/Kg), heat transfer co-efficient (W/m^2K)
H	= head (Kg/cm^2)
k	= conductivity
l	= length (m)
$\dot{m}$	= mass flow rate (Kg/sec)
N	= speed (rps)
P	= pressure (Kg/cm^2)
Q	= heat input (W)
t	= time (s)
T	= temperature (□ K)
V	= volume (m^3)
W	= feed water flow (Kg/sec)
x	= dryness factor
Y	= level (m)

Greek symbol

ρ	= density (Kg/m^3)
α	= Stefan-Boltzman constant

ε = emissivity

μ = kinematic viscosity

Subscripts

air = air

dc = downcomer

dr = drum

e = economiser

f = friction factor

fuel = fuel

g = gas

I = inlet

m = metal

n = water wall section number

o = outlet

p = pump

s = steam

w = water

ww = water wall

References

[1] Hazzab1, A. Laoufi1, I. K. Bousserhane1, M. Rahli "Real Time Implementation of Fuzzy Gain Scheduling of PI Controller for Induction Machine Control"

[2] Hamid Bentarzi, Rabahamr Nadir belaidi Samah "A New Approach Applied to a Thermal Power Plant Controller Using Fuzzy Logic plants"

[3] M. Esfandyari, M. A. Fanaei "Comparsion between classic PID,fuzzy and fuzzy PID controllers"

[4] NTPC Power Plant Model for 500 MW units

[5] Enriquearriag-de-valle and Graciano dieck-Assad "Modelling and Simulation of a Fuzzy supervisory controller for an Industrial Boiler "

[6] A Tanemura,H. Matsumoto Y. Eki S. Nigawara "Expert System for startup scheduling and operation support in fossil power plants"

[7] Xu Cheng ,Richard W. Kephart,Jeffrey J. William "Intelligent Soot blower Scheduling for Improved Boiler Operation"

[8] İlhan, Ertuğrul, Hasan Tiryak "An Investigation Of Productivity In Boilers Of Thermal Power Plants With Fuzzy Gain Scheduled PI controller"

[9] Vjekoslav Galzina, Tomislav Šarić, Roberto Lujić "Application of fuzzy logic in Boiler control"

[10] Bao Gang Hu & George K I Mann, "A systematic study of Fuzzy P I D controllers."P 699-712

[11] T P Blanchett . "PID gain scheduling using fuzzy logic"

[12] Cheng Ling , " Experimental fuzzy gain scheduling techniques"

[13] Energy Research center, Lehigh university, 610-758-4090

[14] Storm RF and Reilly TJ Coal Fired Boiler performance improvement through Combustion optimization