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STATISTICAL PROCESS CONTROL IN AUTOMATED NUCLER REACTOR USING FUZZY LOGIC CONTROLLER

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ABSTRACT

Fuzzy logic controller can be applied to water level control in nuclear power plant to maintain water level in nuclear reactor. Fuzzy logic controller is capable of controlling process using experience of human along with automation. The purpose of this paper is to design a mathematical, physical and simulation modal of fuzzy logic controller for water level control of the reactor in Nuclear Power Plant by using simulation package SIMULINK and Fuzzy Logic Toolbox in MATLAB. The behavior of the system is tested using typical square wave signal as disturbance. The response of the fuzzy controller is then compared with a conventional proportional-integral-derivative (PID) controller. Use of fuzzy logic leads to lower development costs, superior features, and better end product performance.

Keywords: *Fuzzy logic, Statistical Process control, Modeling, Safety, Reactor water level.*

I. INTRODUCTION

1.1 Boiling Water Reactor

Boiling water reactor (BWR) consists of fuel assemblies containing uranium, which are submerged in water which acts as both coolant and moderator (Lamarsh, 1983). The heat generated during fission of uranium in reactor vessel is absorbed by water and itself convert into steam which is transferred through pipes to spin the turbine. The spinning turbine drives the generator to produce electricity. After energy from steam is used to spin turbine, it is drawn into condenser. Steam is cooled and pumped back into the reactor.

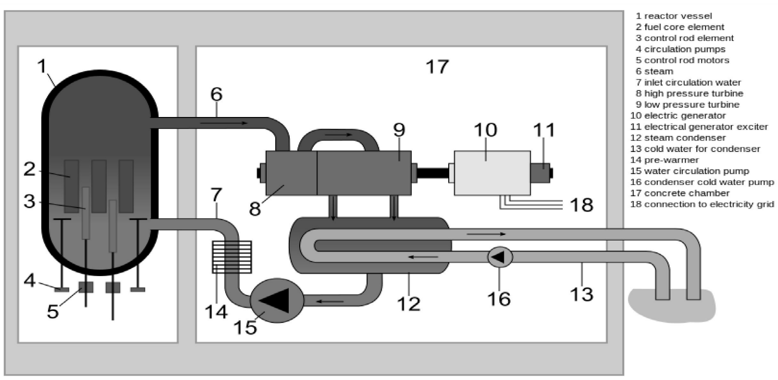

Figure 1: Boiling water reactor (Robert Steffens)

1.2 Process Control for reactor

Reactor power can be controlled via two methods: by inserting or withdrawing control rods and by changing the water flow through the reactor core. In the latter method, when the flow of water in core is increased, steam bubbles quickly gets removed from the core, the amount of liquid water in the core increases, neutron moderation increases, more neutrons are slowed down to be absorbed by the fuel, and reactor power increases. By using the water injection and steam flow rates, the feed water control system can rapidly anticipate water level deviations and respond to maintain water level within a few inches of set point. If all feed water is lost, reactor core meltdown occurs as in Fukushima Diachi Nuclear Disaster in year 2011 leading to radioactive element in atmosphere. Safety is an key element for a process to be lean and efficient.

In this process, there are two inputs: error in liquid level and rate of change of liquid level and one output parameter: the inlet valve control angle.

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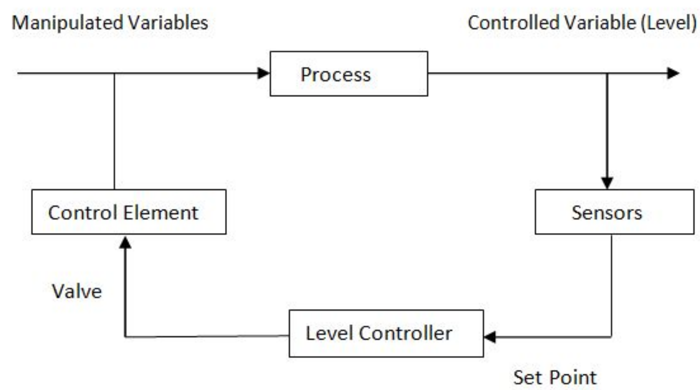

Figure 2: Generalized water level control process

Water level is sensed by a suitable sensor and converted to a signal acceptable to the controller.
The aim of the controller is to regulate the level as close to the set point as possible. The controller compares the level signal to the desired set-point level and actuates the control element or actuator. The control element (say robotic arm) alters the manipulated variable to change position of the valve so that the quantity of liquid being added can be controlled in the process.

1.3 Fuzzy logic Controller

Fuzzy Logic Control (FLC) is obvious and most frequently used approaches for control of process in nuclear reactor. Fuzzy logic is a very emerging intelligent control method which can be applied successfully in nonlinear as well as in linear systems. Fuzzy logic controller can be software or hardware but generally fuzzy codes.

A fuzzy logic based controller uses fuzzy membership functions and inference rules to determine the appropriate process input. Fuzzy logic incorporates the human-like reasoning style of fuzzy systems through the use of fuzzy sets and a linguistic model consisting of a set of IF-THEN fuzzy rules (Ruan, 2000). Fuzzy controller uses linguistic rule base. A fuzzy controller can be broken down into three main components: **Fuzzification** uses defined membership functions to process the inputs and to fuzzify them. It transforms the crisp inputs into linguistic variables. **Knowledge base** is a rule base contains a number of fuzzy if-then rules. A database defines the MFs of the fuzzy sets used in the fuzzy rules. The rules may use several variables both in the condition and the conclusion of the rules. Fuzzy inference engine performs the inference operations on the rules. Finally, **deffuzification** is when the resulting fuzzy set is converted to a number (crisp value) that can be sent to the process as a control signal.
Mandani's prinicipal (COG) takes the input values (rate and level) and finds where they intersect their sets at certain points called alpha cuts. We fire our rules to find the corresponding output rule. The rule is then cut off by the alpha-cut. These shapes are added together to find their total center of gravity of final output. The crisp value x* is given by:

$$X^* = \frac{\int \mu_{control\ action(x)} x\,dx}{\int \mu_{control\ action(x)} dx} \quad \ldots\ldots(1)$$

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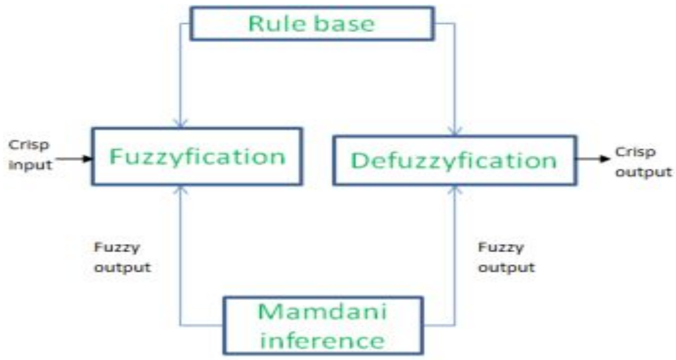

Figure 3: Basic components of fuzzy system

1.4 Application of fuzzy logic controller

i) Water level control for disaster management of floods. This can be used for evacuation to prevent loss of life during flood.
ii) Liquid level control in thermal boilers and process manufacturing.
iii) Autofocus in cameras and distortion pedals for musical instruments.
iv) Cruise control and anti-lock braking system in automotives.
iv) Integrated motion control as in electric motors, CNC and washing machines.
v) Medical diagnostic systems

1.5 Objective

Overall objective of the study is to suggest fuzzy logic controller as a control mechanism for water level controller for domestic and industrial purpose.
The specific objectives are:
i. To understand process control for automation in reactor
ii. To create Physical visual model and mathematical model.
iii. Built simulation model of fuzzy logic controller and
iv. Compare responses of fuzzy logic controller with conventional PID controller

1.6 Outline

The introductory section, section1, consists of introduction of fuzzy logic controller, its application, objective of seminar paper and its limitations. Section 2 presents the literature review. Section 3 presents the methodologies used in the seminar paper. Section 4 has mathematical modeling, section 5 has physical visualization model, and section 6 has simulation of Fuzzy logic controller and PID controller using Fuzzy logic toolbox. Section 7 shows finding and analysis; Section 8 has limitation of study. Section 9 has conclusion and finally section 10 has recommendation for future work.

II. LITERATURE REVIEW

Prof. Lotfi Zadeh in 1965 conceived concept of Fuzzy logic not as a control methodology, but as a way of processing data by allowing partial set membership rather than crisp set membership or non membership(Baldwin, 1996).
Previous research and study has provided with the electrical methods of water level control with a microcontroller-based circuits which automatically predict the liquid levels and accordingly active the circuit to operate motors. Tan (2011) proposed a water level control system for nuclear steam generator. The control system consisted of a feedback controller and a feed forward controller. The robustness and performance of both the controllers are analyzed and tuning of the 2 parameter of the controllers. Kahraman (2006) described application of Fuzzy logic in various industrial setups, and considered it as a great tool for industrial engineers for optimization of process. Safarzadeh, Khaki-Sedigh and Shirani (2011) presented a water level control system for horizontal steam generators using the feedback theory. Zhang and Yang (2012) analyzed the water level control of pressurized water reactor nuclear power station using PID and fuzzy controllers. Reza, Tariq and Reza (2010) designed a water level monitoring and management using electrical conductivity of water. Konar and Konar(1992) explained mamdani

type fuzzy control system for application in Power Control of a Nuclear Reactor which uses centre of gravity for deffuzification.

Park and Seong (1997) investigated self-organizing fuzzy logic controller for water level control of steam generators. Zhang and Hu (2012) investigated performance assessment for the water level control system in steam generator of the nuclear power plant. Shome and Ashok (2012) described an intelligent controller using fuzzy logic to meet the nonlinearity of the system for accurate control of the boiler steam temperature and water level. Mohammad and Taha (2012) described fuzzy logic toolbox to model fuzzy logic controller for water level control. Liu, Peng, Zhao and Li (2009) designed and optimized fuzzy-PID controller for the nuclear reactor power control. Mathworks.com (2014) has provided various example use of Fuzzy logic toolbox. It is feasible to regulate water level in reactor and overall power of the nuclear plant using Fuzzy logic controller, which have better performance than PI controller (Huang, Lee & Edwards, 2002).

III. METHODOLOGY

In this seminar paper following methods has been utilized:
Modeling: Mathematical model and physical visualization modeling of the process control of water level in nuclear reactor was done.
Simulation: Data driven simulation was done using benchmark data available. Fuzzy Logic Toolbox in MATLAB software was used to simulate and generate response for fuzzy logic controller and PID controller to control water level in reactor.

IV. MATHEMATICAL MODEL

Let, tank of area (A) is filled at a flow rate of Q_{in} m^3/sec and discharged at flow rate of Q_{out} m^3/sec. There are three cases for inflow and outflow resulting in water level difference:
a) If $Q_{in} = Q_{out}$, the level, h, remains constant. b) If $Q_{in} > Q_{out}$, the level, h, rises. c) If $Q_{in} < Q_{out}$, the level, h, falls.

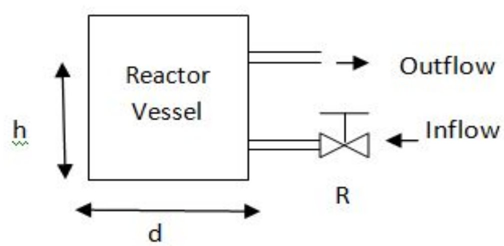

Fig.2.1: Water flow in reactor

Let h be height of reactor and diameter d is constant. R be resistance to flow and is inversely proportional with position of valve. The driving force for the discharge flow is the head of water in the tank which is given by gh
Accumulation is the change in volume (V) with time

$Qin - Qout = A$ (1)

$Qout = gh/R$ (2)

From (1) and (2), we can write:
$+h= Qin$

The equation can be reduced to first order differential equation:
$+ \quad o = K \quad i$ (3)

Where the output, o, is equivalent to height, h; the input, i, is equivalent to the flow in, Qin.

And, From Torricelli Equation: Qout= (4)
Where, a=area of outlet and b= discharge coefficient of valve and g is acceleration due to gravity. Since b is constant, it can be written: Qout= f(h).

Applying the Laplace Transform to (3), we get transfer function for water flow as:

= (5)

So, time constant and gain are: =A/D and K= =D^{-1}
where D=slope at the normal operating level

V. PHYSICAL VISUALIZATION MODEL

To visualize a automated process, replica models and analogous functioning device can be used for being economical yet efficient. Reza et al. (2011) proposed a water level monitoring and management within the context of electrical conductivity of water. Microcontroller based water level sensing and controlling was used. The level of any conductive non corrosive liquids can be measured using this circuit. The circuit is based on 5 transistor switches. Each transistor is switched on to drive the corresponding LED. The electrode probes are kept at various heights in the tank and when in contact with the conducting water, corresponding LED glows. AC voltage is used to prevent electrolysis at the probes. Water level indicator circuit can be interfaced with the microcontroller. The Fuzzy Inference System stored inside the microcontroller using fuzzy logic which can perform suitable control action to turn ON/OFF valve.

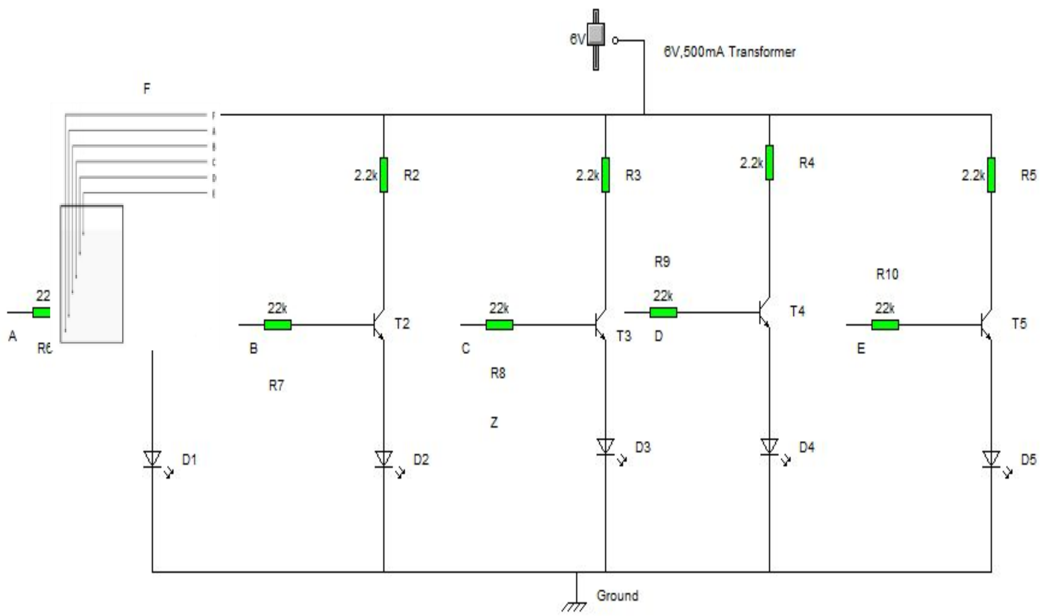

Figure 4: Water level controller circuit and probes (Reza et al., 2010)

VI. SIMULATION

6.1 Simulink model

A continuous square wave is applied at the input to the controller for creating continuous disturbance. Another input to the controller comes from feedback. The controller takes the action according to the error generated. This error and its derivative is applied to the controller which then takes the necessary action and decides the position of the valve which gives the desired flow of the liquid into the tank. The positioning of the valve is decided by PID Controller or by the rules written in the Fuzzy Logic Controller Rule Editor. If the liquid level in the tank is low then the valve open completely and if the liquid level is high in the tank then the valve closes or opens to an extent. When the level is full then the valve closes completely (Reza et al., 2010).

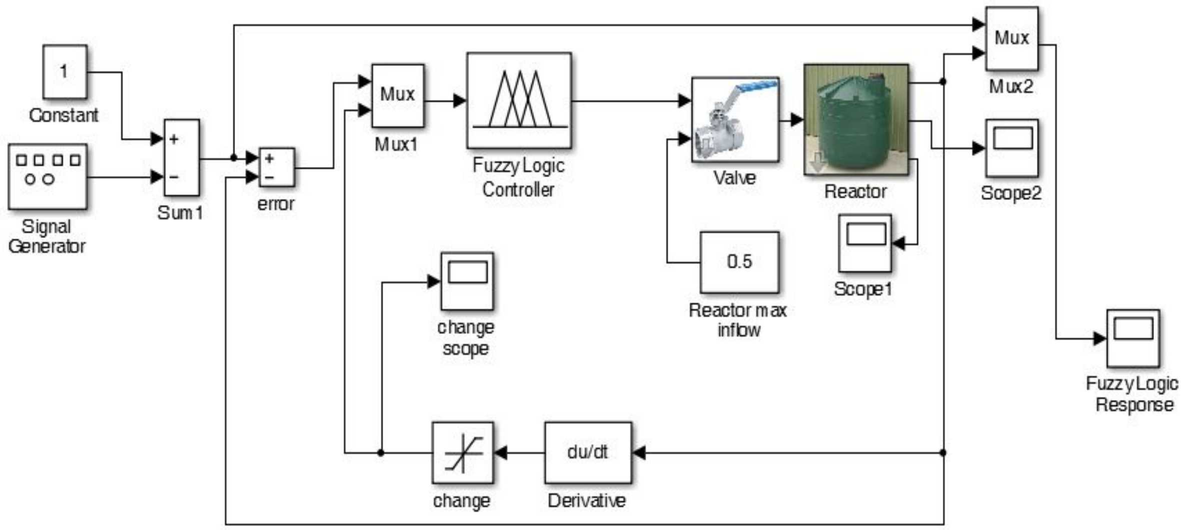

Figure 5: SIMULINK model for Fuzzy Controller for Water level control in reactor

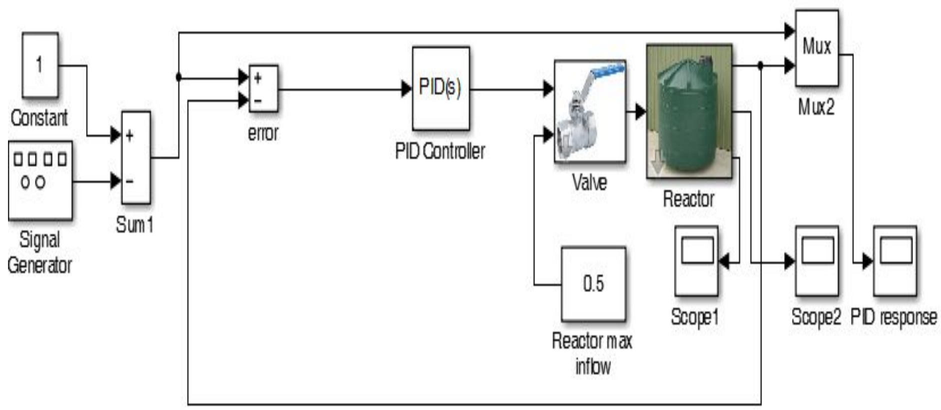

Figure 6: SIMULINK model for PID controller for water level control in reactor

6.2 Fuzzy logic toolbox

Statistical membership function can be used to represent an industrial process and its analysis. For a process which is continuous and can be parameterized by mean and standard deviation, Gaussian distribution can be used to represent such process or the fuzzy set. For output with unpredictable characters, triangular function can be used to represent the fuzzy set.

The non linear model is made linear using SIMULINK which simplifies the analysis of this model (Mathworks.com, 2014). With all of the input and output membership functions and rule base for the we can increase water inflow when the error is positive, and stop flow of water if the error is moving towards zero rapidly to prevent overshoot. So if the error is okay we want to open or close the valve slowly, but if the error is negative or positive we want to open or close fast. The rules used are shown in the rule editor in Figure 12.

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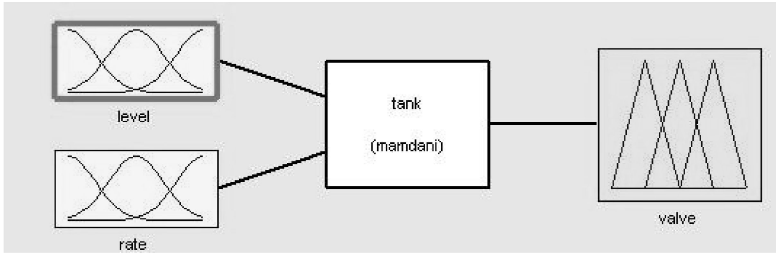

Figure 7: Mamdani type Fuzzy Controller

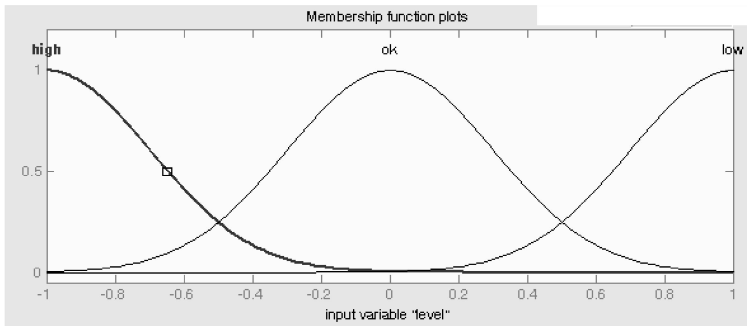

Figure 8: Membership function Fuzzy Set characterizing the Input

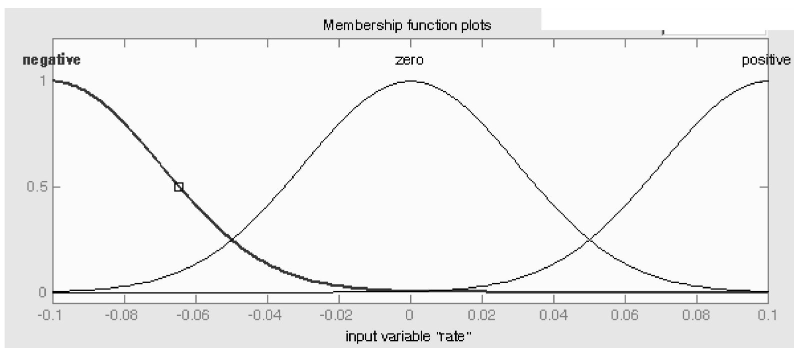

Figure 9: Membership function Fuzzy Set characterizing the Input

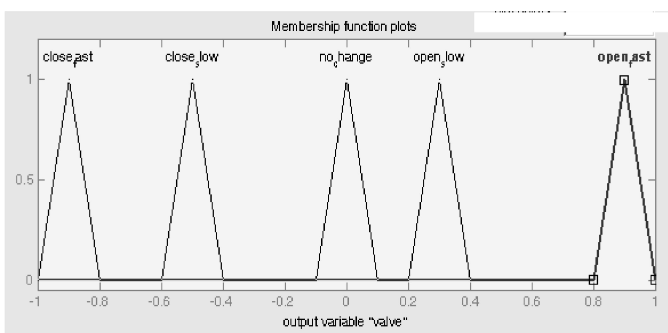

Figure 10: Membership function Fuzzy Set characterizing the output

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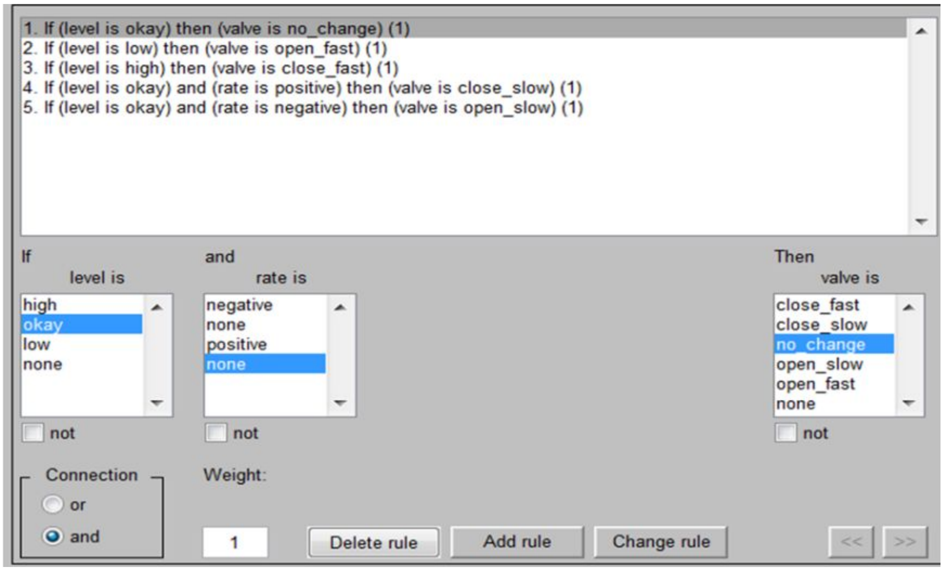

Figure 11: Rule Editor

Parameter	Range	Membership Function	Fuzzy Variable	Crisp Range
Level	-1 to 1	Gaussian	High	(0.3,-1)
			Ok	(0.3,0)
			Low	(0.3,1)
Rate	-1 to 1	Gaussian	Negative	(0.3,-1)
			Zero	(0.3,0)
			Positive	(0.3,1)
Valve	-1 to 1	Triangular	Close_fast	(-1.0 -0.9 -0.8)
			Close_low	(-0.6 -0.5 -0.4)
			No_change	(-0.1 0 0.1)
			Open_slow	(0.2 0.3 0.4)
			Open_fast	(0.8 0.9 1.0)

Table 1: Summary for characters of input and output (Huang, Lee & Edwards, 2012)

VII. FINDINGS AND ANALYSIS

7.1 Output of fuzzy logic controller

Rule viewer allows interpreting entire fuzzy logic interface process at once. Rule base consisting of five rules but can be maximum up to 81 rules for 2 inputs, will be activated to follow-up the desired liquid level. The rule viewer is used to get the crisp defuzzified values for the corresponding crisp inputs. The final result is shown as the red line in the output. *Fig. 4.1* shows when the value of the level is 0.189 and the rate is 0.005 then the value of valve is -0.0244.Here, fuzzy control action is converted to crisp control action using method centroid of gravity method.

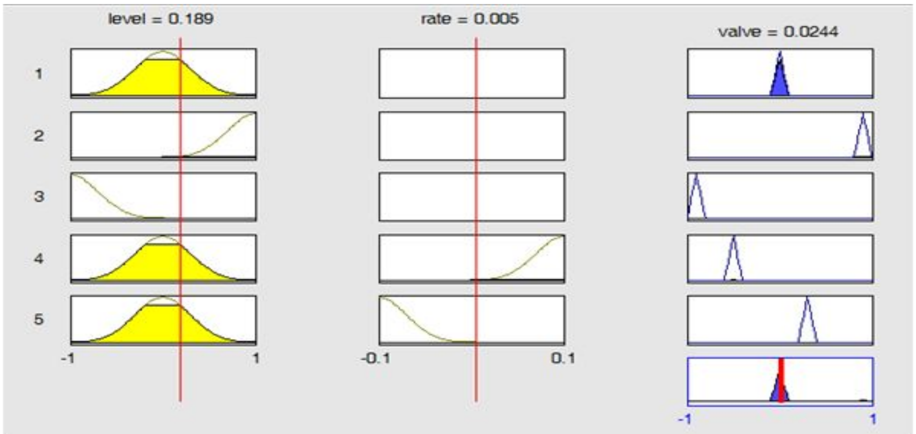

Figure 12: Rule viewer

7.2 Comparison of response of PID and Fuzzy logic controller

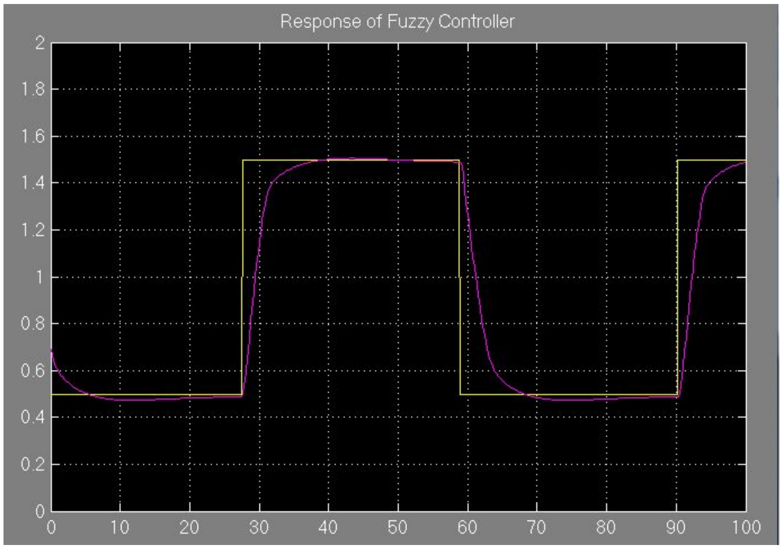

Figure 13: Response of fuzzy controller (Left) and PID controller (Right)

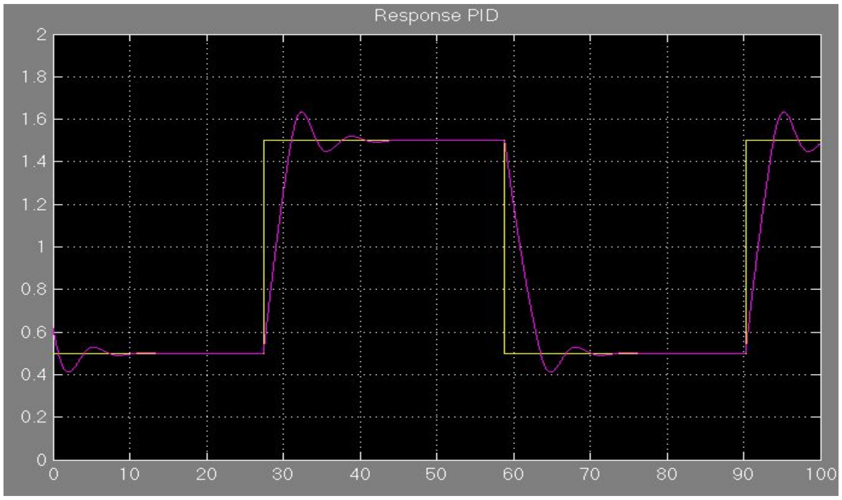

Figure 14: Response of PID controller

The comparison of fuzzy and PID controller transient response for 2.5m desired level shows PID controller has a large overshoot (δ) compared to the fuzzy controller and also takes a lot of time to stabilize at the desired level, so settling time is more for PID controller. Fuzzy logic on the other hand, has little overshoot and steady state error and stabilizes quickly providing accurate level control.

VIII. LIMITATIONS

i) Fuzzy logic controller could not be optimized by fine tuning parameters and validating model due to lack of actual real life data.
ii) The controller is based on Mamdani inference which updates FLC parameters heuristically.
iii) The simulation could not be tested in real life situation due to lack of hardware setup.

IX. CONCLUSION

Process can be represented by fuzzy sets which can be uniquely associated and described by a membership function. The fuzzy logic based controller to control water level in nuclear reactor of boiling water reactor which was modeled and simulated using SIMULINK and Fuzzy logic toolbox in MATLAB, showed that process control and automation can be achieved using fuzzy logic controller.

The comparison result of response of fuzzy logic controller with conventional PID controller showed better performance of the fuzzy logic controller in terms of steady state error, settling time and overshoot.

X. FURTHER STUDY

a. He fuzzy logic controller can be modeled using temperature or reactivity for the process control of nuclear reactor.
b. He simulated model can be validated and fine tuned using real hardware and data obtained.
c. He number of rules can be increased to accommodate all the possible real life situations.

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