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Temperature and Water Level Control in Boiler by using Fuzzy Logic Controller

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Abstract

Boiler is the main component in generating steam in thermal and nuclear power generation units, and its control is very important. Water level control is more important such as boilers in thermal and nuclear power plants. This work proposed a simple fuzzy logic based water level controller. The fuzzy logic controller uses the MAMDANI type Fuzzy Inference System. The fuzzy controller has two inputs; feed backs from temperature sensors and water level sensor is given to the fuzzy controller and the controlled output is generated for output valve position. The fuzzy controller is implemented in MATLAB and then simulated in SIMULINK to test the behaviour of the system when the two inputs change. The response of the fuzzy controller is then compared with a conventional PID controller. In control systems there are a number of generic systems and methods which are encountered in all areas of industry and technology. The results are shown sequentially and the effectiveness of the controller is illustrated.

***Keywords**: Boiler temperature control, fuzzy logic control, inference engine, water level control, PID control, fuzzy inference system*

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INTRODUCTION

In processes of thermal and nuclear power generation; control of water level and boiler temperature is required. It is known that about 25% of emergency shutdowns in the nuclear power plant are caused by poor control of water level in the steam generator. Such shutdowns greatly decrease the plant outputs and their efficiency and must be minimized. Water level control system is a very complex system, because of its nonlinearity and uncertainty [1]. Currently, constant gain PID controllers are used in nuclear organizations for boiler water level control at high power operations. However, at low power operations, PID controllers cannot maintain water level properly. A need for performance improvement of existing water level regulators is therefore required [2–3].

There are several reasons for using automatic temperature controls for steam applications. For some processes, it is necessary to control the product temperature to within fairly close limits to avoid the product or material being processed, being spoilt [4]. Steam flashing from boiling tanks produces not only unpleasant environmental conditions, but can also damage the fabric of the building. Automatic temperature controllers can keep hot tanks just below boiling temperature [5].

CURRENT SCENARIO OF BOILER CONTROL

If the steam consumed is less than the maximum, pressure is built-up in the generator chamber until it reaches the pressure limit set by the pressure regulator. At this point the pressure regulator valve partially closes, reducing the amount of steam entering the regulating chamber [6]. This unbalances the system momentarily, permitting the water to rise in the regulating chamber due to the higher pressure condition in the generating chamber. As the water level drops in the generating chamber the electrodes are progressively exposed, and the amount of steam being generated decreases [7]. As much as current input is proportional to the immersed area of the electrodes, the falling water level reduces the electric input. Conversely, if heavy use of steam tends to lower the desired pressure, the regulating valve opens wide, allowing more steam into the regulating chamber [8]. This forces water, back into the generating chamber and increases the flow of current and rate of steam production by completely enveloping the electrodes. The water level in both chambers is rarely balanced. This condition occurs only at full load.

Figure 1 shows the proposed FLC based boiler control system. The proposed method consists of two sections. First section is to develop a steam temperature monitoring and control system and the second section consists of water level control. For both of the sections fuzzy logic control will be used. The temperature sensor will be interfaced with the fuzzy controller to monitor the steam temperature and a water level control circuit will be interfaced with the fuzzy controller which will indicate the water level inside the boiler chamber. The fuzzy controller will take the temperature sensor output and water level indicator output as the two inputs for the fuzzy inference system. After fuzzification of the inputs and applying suitable rules and defuzzifying the output the fuzzy controller generates appropriate control signals.

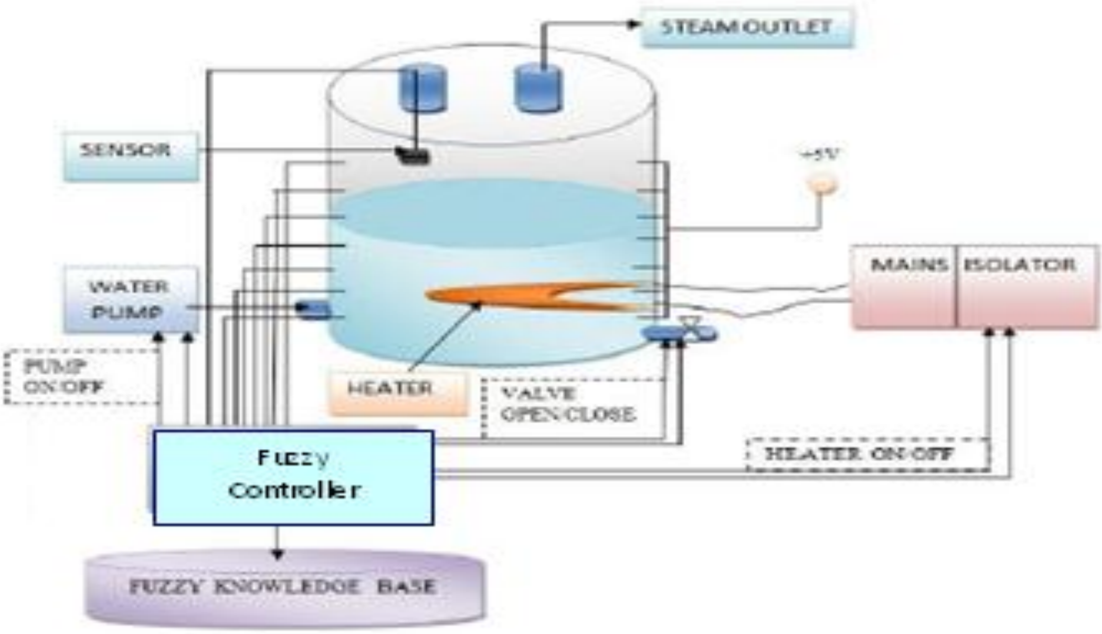


Fig. 1: *Proposed FLC Based Boiler Control System.*

WATER TANK SYSTEM

In general, the flowing of water is supplied via a pump set from a storage tank and water flow rate is adjusted with an actuator. Figure 2 shows the schematic of such a surge tank system.

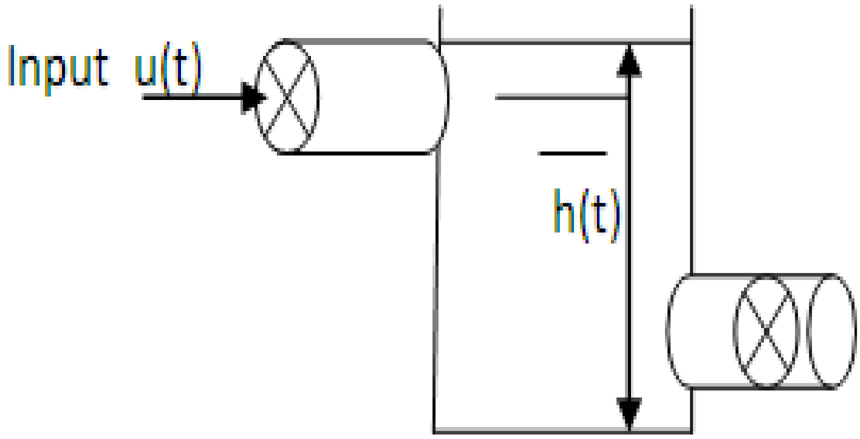


Fig. 2: *Surge Tank System.*

The level of water is measured through a pressure transmitter. The transmitted pressure data is transferred to control circuit. The system model can be represented as a first order differential equation,

$$\frac{dh(t)}{dt} = -c\frac{\sqrt{2gh(t)}}{A} + \frac{1}{A}u(t) \qquad (1)$$

Here, u(t) is the input flow (control input), which can be positive or negative that can both pull out the water from tank or put it in, h(t) is the water level (the output of the plant), A= $\sqrt{ah^2(t)+b}$ is the cross-sectional area of the tank, g=9.8 m/s2 is acceleration due to gravity and c is known cross-sectional area of the output pipe.

There are various approaches to the design of the water level controllers. The tank dynamics model based proportional integral derivative (PID) controllers have become famous for thermal and nuclear boiler water level control.

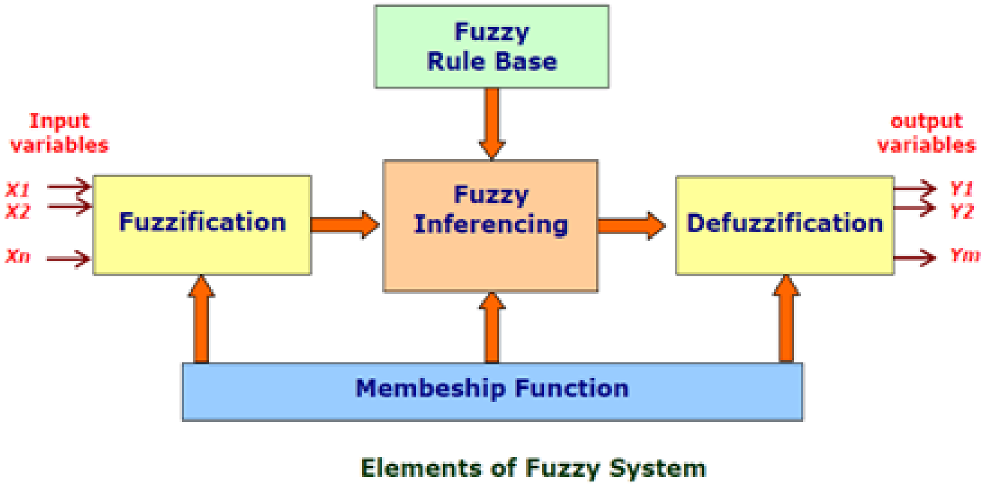
INTELLIGENT CONTROL METHOD

Conventional control approaches are not convenient to solve the complex issues in this highly nonlinear system. Fuzzy logic control have emerged over the years and become one of the most active areas of research.

There are many works in literature which addressed the water level control issues using fuzzy logic controller. Due to its simplicity, fuzzy logic control method becomes most famous in this application. Fuzzy logic is a form of probabilistic logic it deals with approximate reasoning rather than fixed and exact.

Unlike traditional binary sets, where variables take either true or false values, fuzzy logic variables have a truth value that ranges in degree between 1 and 0. The truth value may range between completely true and completely false.

Thus fuzzy logic has been extended to handle the concept of partial truth. Fuzzy logic is a part of artificial intelligence or machine learning which interrupts a human's actions. Computers can interpret only true or false values but a human being can reason the degree of truth or degree of falseness. Fuzzy models interpret the human actions and are also called intelligent systems.



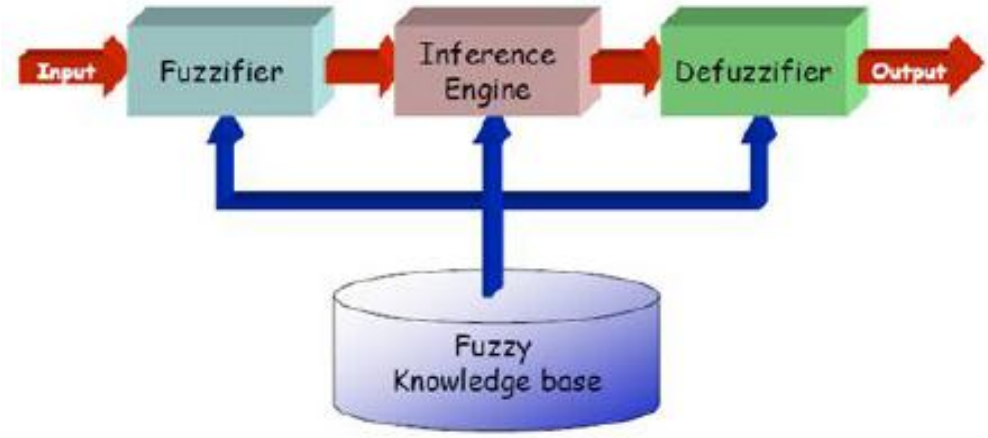


Fig. 3: *A General model of Fuzzy Interface System.*

A fuzzy set is an extension of a crisp set. Crisp sets allow only full membership or no membership at all, whereas fuzzy sets allow partial membership. In a crisp set, membership or non-membership of element x in set A is described by a characteristic function. Fuzzy set theory extends this concept by defining partial membership. A fuzzy set 'A' on a universe of discourse U is characterized by a membership function that takes values in the interval. Fuzzy sets represent common sense linguistic labels like slow, fast, small, large, heavy, low, medium, high, tall, etc. A given element can be a member of more than one fuzzy set at a time. A membership function is essentially a curve that defines each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. It provides a measure of the degree of similarity of elements in the universe. Various types of membership functions are used, including triangular, trapezoidal, generalized bell shaped, Gaussian curves, polynomial curves, and sigmoid functions. A fuzzy inference system (FIS) essentially defines a nonlinear mapping of the input data vector into a scalar output, using fuzzy rules. The mapping process involves input/output membership functions, FL operators, fuzzy if–then rules, aggregation of output sets, and defuzzification. An FIS with multiple outputs can be considered as a collection of independent multi-input, single-output systems. A general model of a fuzzy inference system (FIS) is shown in Figure 3. The FIS maps crisp inputs into crisp outputs. It can be seen from the figure that the FIS contains four components: the fuzzifier, inference engine, rule base, and defuzzifier. The rule base contains linguistic rules that are provided by experts. It is also possible to extract rules from numeric data. Once the rules have been established, the FIS can be viewed as a system that maps an input vector to an output vector. The fuzzifier maps input numbers into corresponding fuzzy memberships. This is required in order to activate rules that are in terms of linguistic variables. The fuzzifier takes input values and determines the degree to which they belong to each of the fuzzy sets via membership functions.

The inference engine defines mapping from input fuzzy sets into output fuzzy sets. It determines the degree to which the antecedent is satisfied for each rule. If the antecedent of a given rule has more than one clause, fuzzy operators are applied to obtain one number that represents the result of the antecedent for that rule. It is possible that one or more rules may fire at the same time. Outputs for all rules are then aggregated. During aggregation, fuzzy sets that represent the output of each rule are combined into a single fuzzy set. Fuzzy rules are fired in parallel, which is one of the important aspects of an FIS. In an FIS, the order in which rules are fired does not affect the output.

TYPES OF FUZZY LOGIC SYSTEMS

There are two major types of control rules in fuzzy control:

1) Mamdani System: This method is widely accepted for capturing expert knowledge. It allows us to describe the expertise in more intuitive, more human-like manner. However, Mamdani-type FIS entails a substantial computational burden.
2) Takagi-Sugeno: This method is computationally efficient and works well with optimization and adaptive techniques, which makes it very attractive in control problems, particularly for dynamic non-linear systems. These adaptive techniques can be used to customize the membership functions so that fuzzy system best models the data.

The most fundamental difference between Mamdani-type FIS and Sugeno-type FIS is the way the crisp output is generated from the fuzzy inputs. While Mamdani-type FIS uses the technique of defuzzification of a fuzzy output, Sugeno-type FIS uses weighted average to compute the crisp output.

The expressive power and interpretability of Mamdani output is lost in the Sugeno FIS since the consequents of the rules are not fuzzy. But Sugeno has better processing time since the weighted average replace the time consuming defuzzification process. Due to the interpretable and intuitive nature of the rule base, Mamdani-type FIS is widely used in particular for decision support application. Other differences are that Mamdani FIS has output membership functions whereas Sugeno FIS has no output membership functions. Mamdani FIS is less flexible in system design in comparison to Sugeno FIS as latter can be integrated with ANFIS tool to optimize the outputs. Major benefits of fuzzy logic approach over the other methods are,

1. Fuzzy logic possesses the ability to mimic the human mind to effectively employ modes of reasoning that is approximate rather than exact.
2. Fuzzy logic can model nonlinear functions of arbitrary complexity to a desired degree of accuracy.
3. Perform better than the conventional PID controllers.
4. Fuzzy logic is a convenient way to map an input space to an output space. Fuzzy logic is one of the tools used to model a multi-input, multi-output system.
5. It is simple to design and implement.

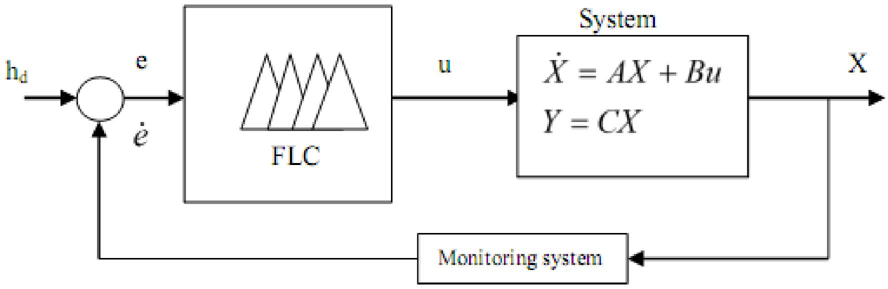
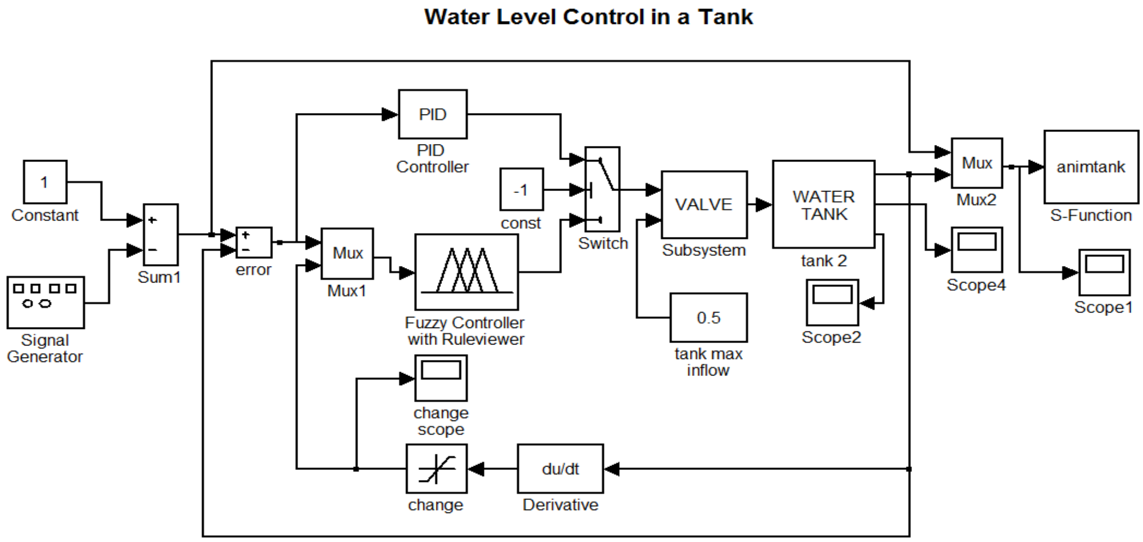


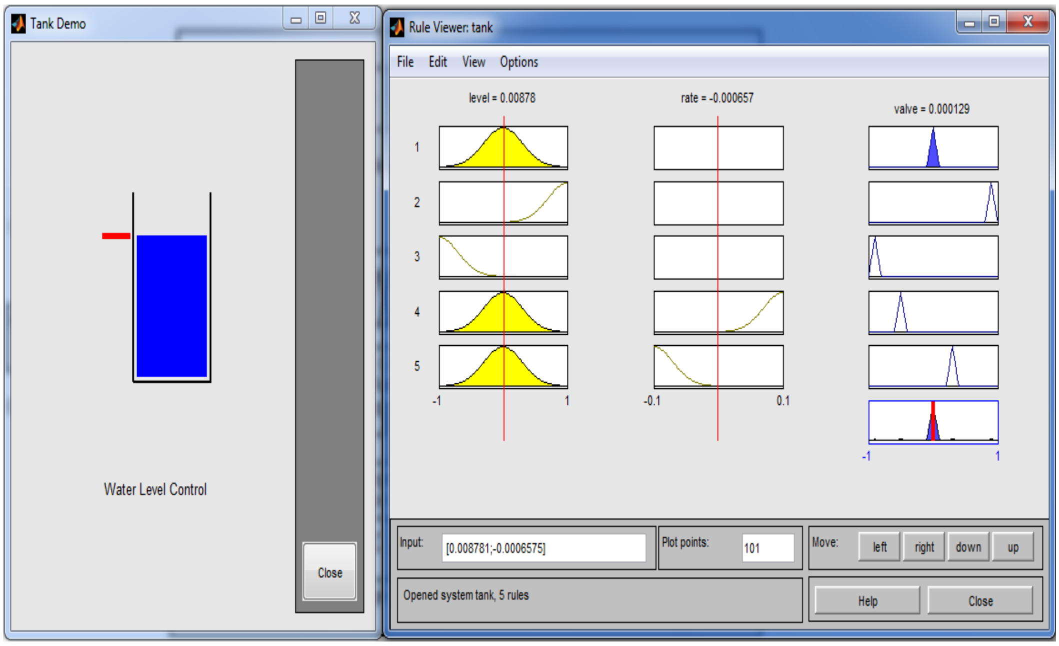
Fig. 4: *FLC Control System.*

The fuzzy logic controller (FLC) acts as a part of the control system just like in conventional control systems. Figure 4 shows the FLC system with system described in state-space form.

SIMULATION RESULTS AND DISCUSSION

When the value of the level is 0.00878 and the rate is –0.000657 then the value of valve is 0.000129.





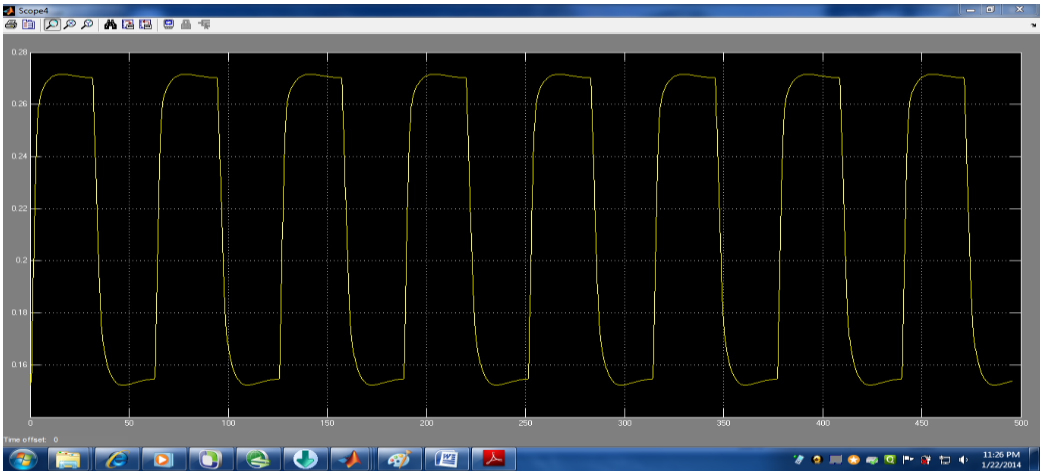


Fig. 5: Water Tank Level.

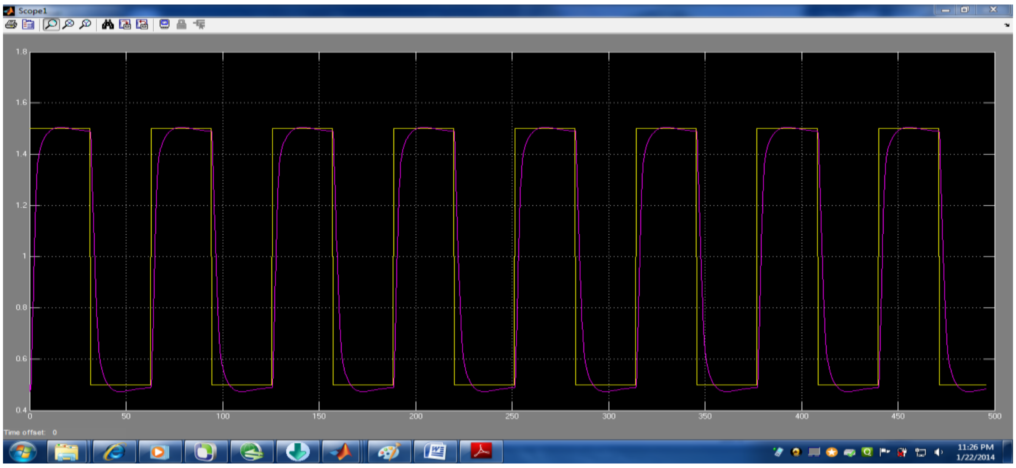
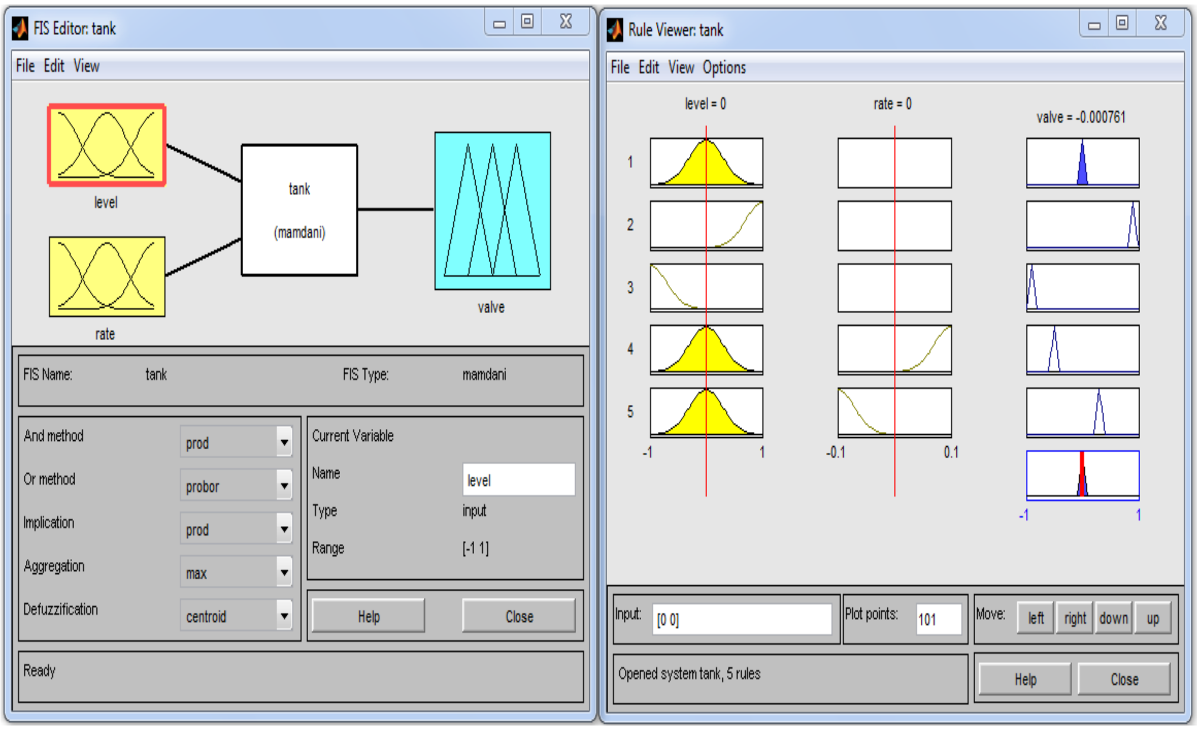
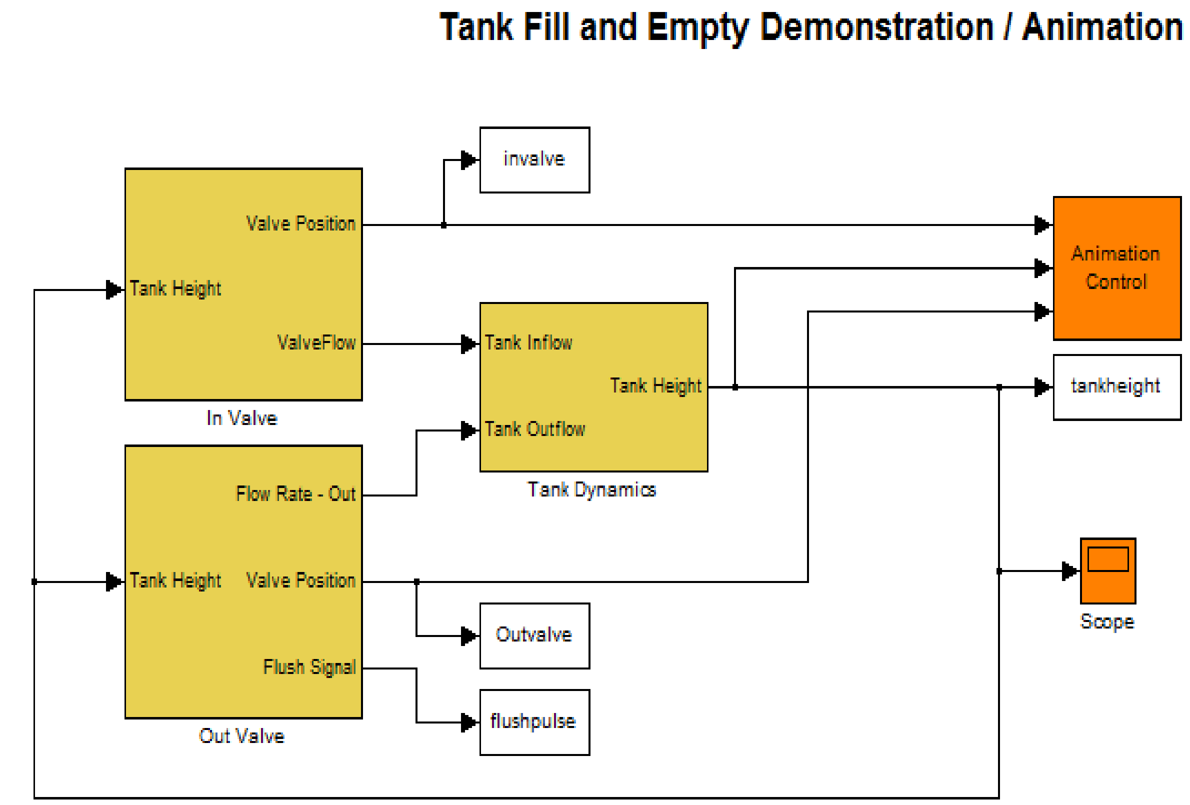
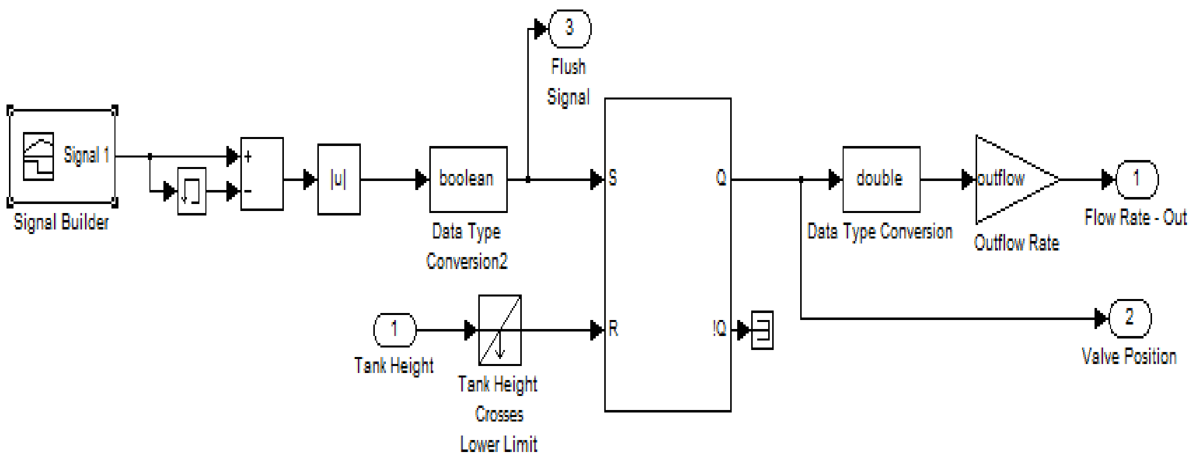


Fig. 6: Maximum Water Level.




Tank Fill and Empty Demonstration / Animation
invalve
Valve Position
Tank Height
ValveFlow
In Valve
Tank Inflow
Tank Height
Tank Outflow
Tank Dynamics
Animation Control
tankheight
Flow Rate - Out
Tank Height
Valve Position
Flush Signal
Out Valve
Outvalve
flushpulse
Scope


Signal 1
Signal Builder
|u|
boolean
Data Type Conversion2
3
Flush Signal
S
Q
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double
Data Type Conversion
outflow
Outflow Rate
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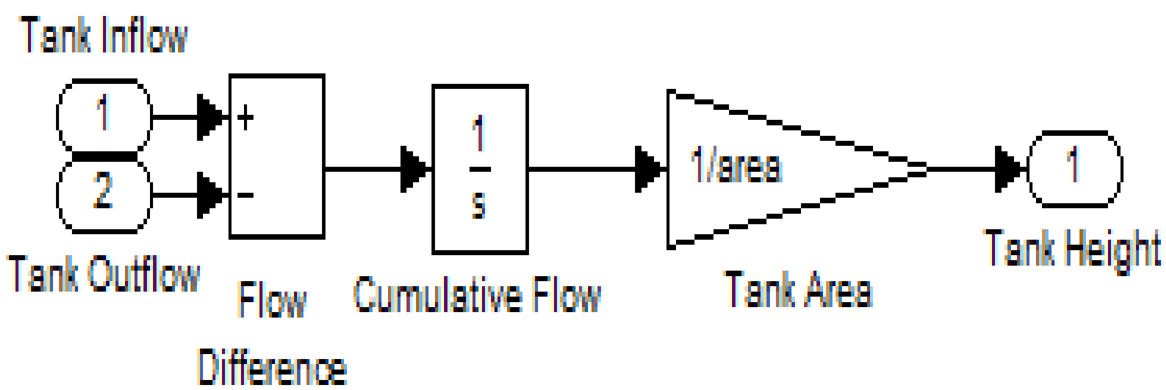
Flow Rate - Out
2
Valve Position
1
Tank Height
Tank Height Crosses Lower Limit


Tank Inflow
1
2
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Flow Difference
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Tank Area
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Tank Height

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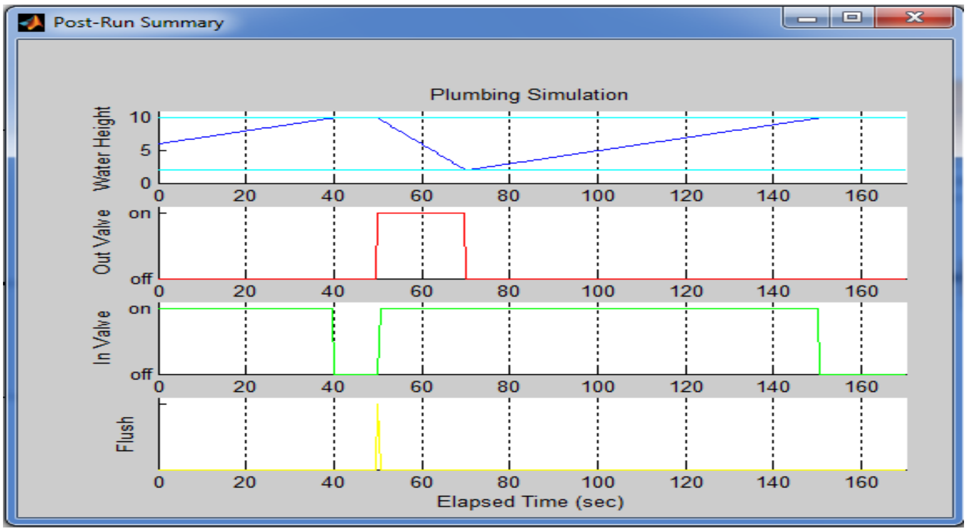

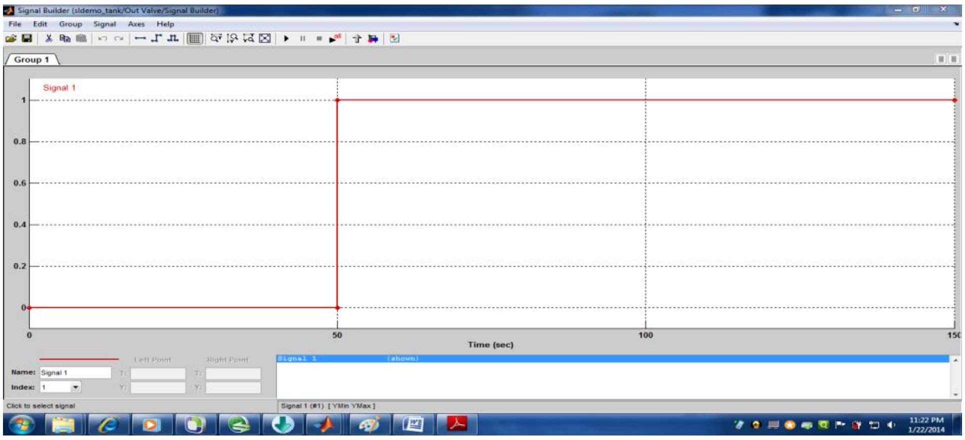

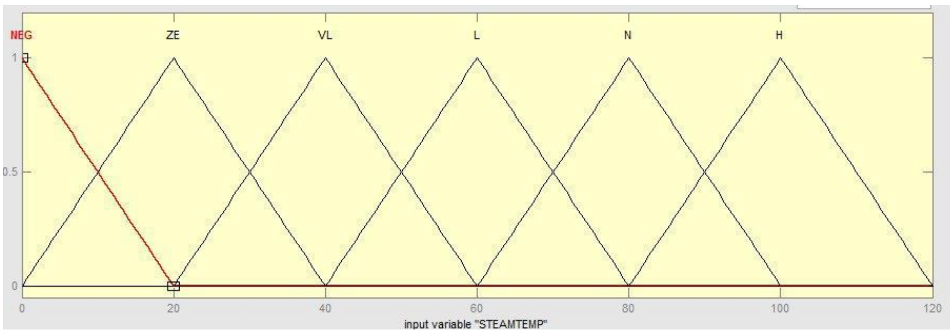

***Fig. 7:** Input Membership Function: STEAMTEMP.*

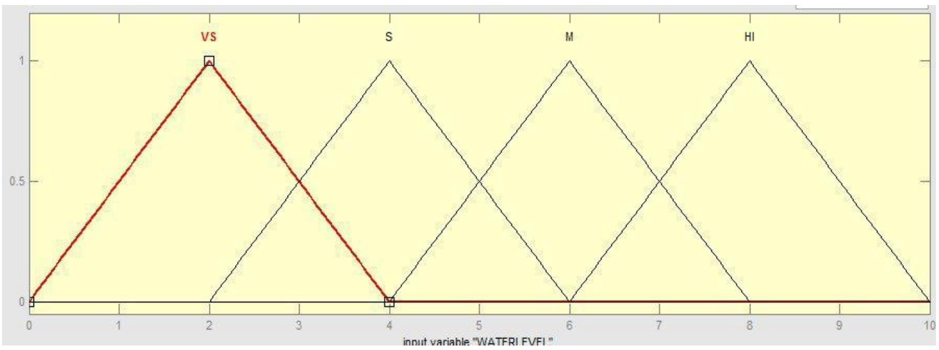

***Fig. 8:** Input Membership Function: WATERLEVEL.*

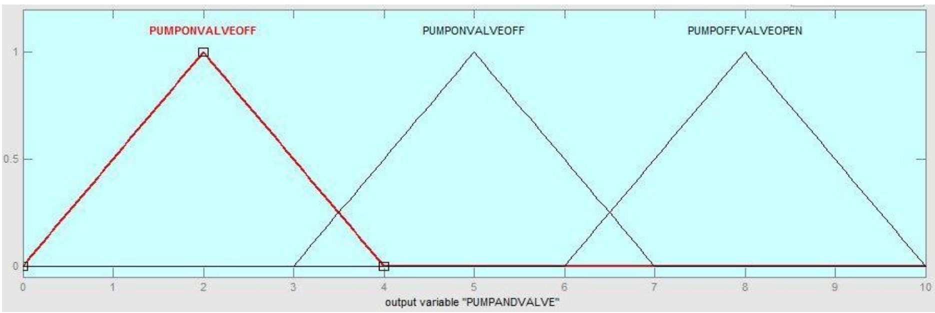

Fig. 9: *Output Membership Function: PUMPANDVALVE.*

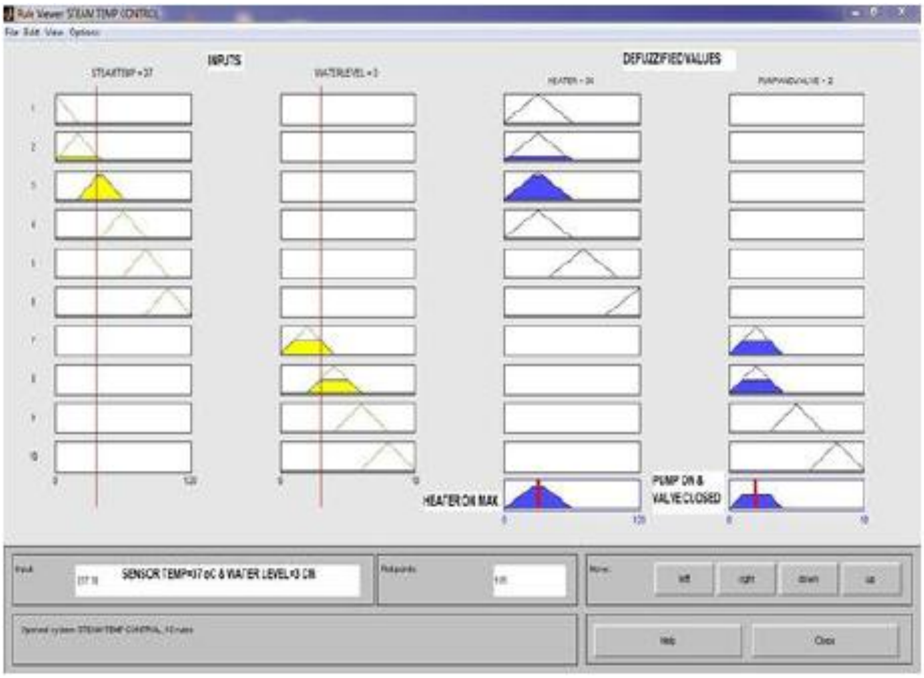

Fig. 10: *Simulated Output when Steam Temp=37°C and Water Level=3 cm.*

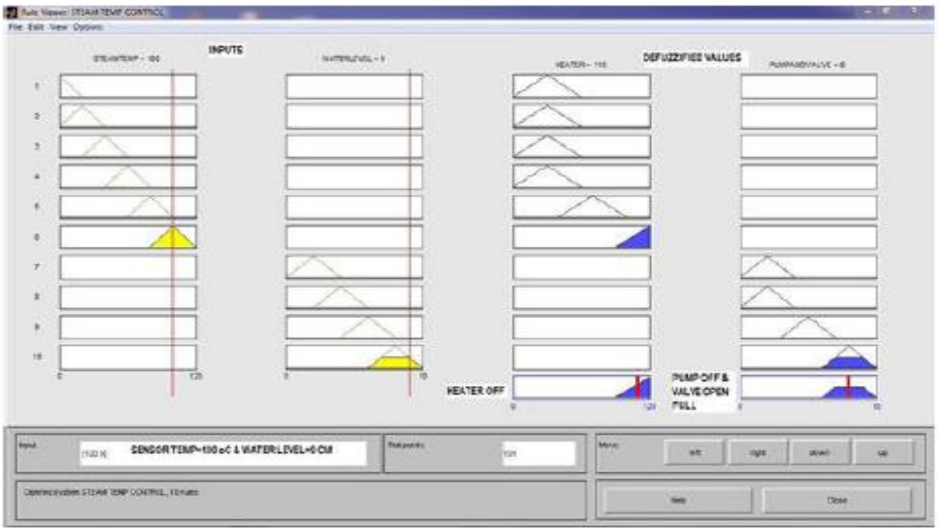

Fig. 11: *Simulated Output when Steam Temp=100°C and Water Level=9 cm.*

CONCLUSION

The fuzzy logic based boiler temperature monitoring and control and water level control inside the boiler chamber is simulated successfully and the results are also verified. So, we can conclude that the fuzzy logic based boiler temperature and water level control is working properly and the results obtained. Based on the existing MATLAB fuzzy logic toolbox demo, the controller is implemented and simulated successfully. This unconventional control approach can be used in boiler water level and also temperature control applications of nuclear/thermal power plants. As a future scope of this work the FLC can be implemented in a microcontroller with additional set of rules for more accurate control and can be used in various applications in industry and household. The controller can also be tested with periodically varying water level tracking applications.

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