BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCES, PILANI

ELECTRONICS CIRCUIT LAB PROJECT

DESIGNING A FUZZY LOGIC TANK LEVEL CONTROLLER

Instructor: Prof. Yenuganti Sujan

Submitted By: (Group-4)

Ayush Agrawal - 2018A8PS0469P

Saurav Biyani – 2018A3PS0461P

Chivukula Uday Bhargav – 2018A3PS0315P

Daksh Dave – 2018A3PS0391P

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ABSTRACT:

Water level control is highly important in industrial applications such as boilers in nuclear power plants. In this work a simple water level indicator and a water level controller based on fuzzy logic is proposed. Fuzzy logic is a part of artificial intelligence and machine learning which can mimic a human mind. Fuzzy logic system is an excellent choice for many control applications since it mimics human control logic. It is very useful in converting real life time problems into linguistic variables. Fuzzy logic control has been successfully utilized in various industrial applications; it is generally used in complex control systems, such as chemical process control. Today, most of the fuzzy logic controls are still implemented on expensive high-performance processors. In our model, we use the Mamdani fuzzy logic model. First, the mathematical model of the process was modelled using MATLAB. Then, based on the existing MATLAB fuzzy logic toolbox, the controller is implemented and simulated successfully and the results are being presented in this report and are compared to the performances of PID controller when used on the same plant. Simulation and experimental results are presented followed by a comparison of the fuzzy controller with respect to the PID controller.

Intelligent Control Methods:

Intelligent control is a class of control techniques that use various artificial intelligence computing approaches like neural networks, Bayesian probability, fuzzy logic, machine learning, reinforcement learning, evolutionary computation and genetic algorithms.

Intelligent control can be divided into the following major sub-domains:

- Neural network control
- Machine learning control
- Reinforcement learning
- Bayesian control
- Fuzzy control
- Neuro-fuzzy control
- Expert Systems
- Genetic control

New control techniques are created continuously as new models of intelligent behavior are created and computational methods developed to support them

Fuzzy Logic:

Fuzzy logic is a part of artificial intelligence or machine learning which interprets a human's actions. Fuzzy techniques have been successfully used in control in several fields. Fuzzy logic is a form of logic whose underlying modes of reasoning are approximate instead of exact.
s. The general idea about fuzzy logic is that it takes the inputs from the sensors which is a crisp value and transforms it into membership values ranging from 0 to 1.

The Fuzzy Logic controller consists basically of four parts: fuzzification interface, knowledge base, inference engine, and a defuzzification interface. Fig. 1 shows the basic configuration of a fuzzy logic controller.

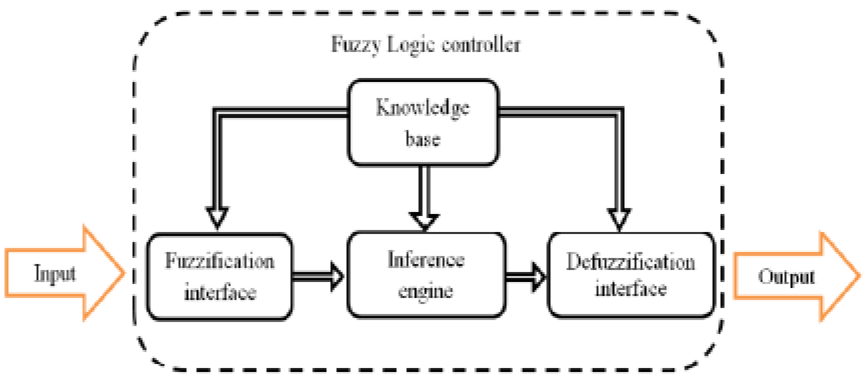


Fig 1: Basic configuration of a Fuzzy logic controller

Each of these parts plays a different role in the control process and affects the performance of the controller and the behavior of the whole system.

A. Fuzzification

In fuzzy control theory, an input variable is converted into a fuzzy variable by a process known as fuzzification. Each fuzzy variable consists of a group of fuzzy sets.
The information fuzzification consists in fuzzy values assumption of input measures, respectively output in/from controller. Fuzzification is the process of making a crisp quantity fuzzy. The fuzzification interface involves the following functions:
i) Measures the value of input variables;

(ii) Performs a scale mapping that transfers the range of values of input variables into corresponding universes of discourse; and
iii) Performs the function of fuzzification that converts input data into suitable linguistic values which may be viewed as labels of fuzzy sets.

B. Fuzzy rules

A fuzzy system is characterized by a set of linguistic statements based on expert knowledge. The knowledge base comprises knowledge of the application domain and the attendant control goals. It consists of a ‘database’ and a ’rule base’. The database provides necessary definitions which are used to define linguistic control rules and fuzzy data manipulation. Generally, the design of fuzzy controllers is based on the operator’s understanding of the behavior of the process instead of its detailed mathematical model. The main advantage of this approach is that it is easy to implement ‘rule of thumb ‘experiences and heuristics. These rules are often expressed using syntax of the form: If <fuzzy proposition>, then <fuzzy proposition >, where the fuzzy propositions are of the form, ‘x is Y’ or ‘x is not Y ‘, x being a scalar variable and Y being a fuzzy set associated with that variable. This rule establishes a relationship or association between the two propositions.

C. Fuzzy Inference

Fuzzy inference is the kernel in a fuzzy logic system. It has the capability of simulating human decision making based on fuzzy concepts and of inferring fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic. In the fuzzy inference engine, fuzzy logic principles are used to combine fuzzy 'IF-THEN' rules from the fuzzy rulebase into a mapping from fuzzy input sets to fuzzy output sets.

D. Defuzzification

The defuzzification interface performs the following functions:

(i) Scale mapping which converts the range of values of output variables into corresponding universes of discourse; and
(ii) Defuzzification, which yields a non-fuzzy control action from an inferred fuzzy control action.
Defuzzifier produces a crisp output for our fuzzy logic system from the fuzzy set that is the output of the inference block.

Types of fuzzy logic systems

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

A. Mamdani System

Mamdani System is extensively acknowledged for capturing expert knowledge. It permits us to describe the expertise in a more intuitive, more human-like manner. But, Mamdani-type FIS involves a considerable mathematical load.

B. Takagi- Sugeno

This method is mathematically competent and works well with optimization and adaptive techniques, which makes it very attractive in control problems, particularly for dynamic non-linear systems. The 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 employs defuzzification of a fuzzy output, Sugeno-type FIS employs weighted average to compute the crisp output. The expressive power and interpretability of Mamdani output is lost in the Sugeno FIS since the consequences of the rules are not fuzzy. But Sugeno has better processing time because the weighted average replaces 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.

Benefits of fuzzy logic:

Major benefits of fuzzy logic approach over the other methods are:
a. Fuzzy logic possesses the ability to mimic the human mind to effectively employ modes of reasoning that are approximate rather than exact.
b. Fuzzy Logic can model nonlinear functions of arbitrary complexity to a desired degree of accuracy.
c. Perform better than the conventional PID controllers.
d. 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.
e. It is simple to design and implement.
f. Fuzzy logic is conceptually easy to understand.
g. Fuzzy logic is flexible.
h. Fuzzy logic is tolerant of imprecise data.
i. Fuzzy logic can be built on top of the experience of experts.
j. Fuzzy logic can be blended with conventional control techniques.
k. Fuzzy logic is based on natural language.

Fuzzy controller

The purpose of any plant controller is to relate the state variables to action variables. The controller of a physical system need not itself be physical but may be purely logic. Furthermore, where known relationships are vague and qualitative. A Fuzzy logic controller may be constructed to implement the known heuristic.

The fuzzy logic controller usually works with more than two input signals, the system error e(k) and the change rate in the error Δe(k). The error of the system is defined as the difference between the set point yr(k) and the plant output y(k) at a moment k:

$$e(k) = y_r(k) - y(k) \qquad (4)$$

The variation of the error signal at the moment k is given by the following equation:

$$\Delta e(k) = e(k) - e(k-1) \qquad (5)$$

Thus, in such a controller the variables are equated to a non-Fuzzy universe given the possible range of measurement or action magnitudes. These variables, however, take on linguistic values which are expressed as Fuzzy subsets of the universe. The complete procedure of the fuzzy controller design was described. Fuzzy control can be described as a means of control working with sentences rather than equations. Fuzzy control is based on an I/O function that maps each very low-resolution quantization interval of the input domain into a very low-low resolution quantization interval of the output domain. As there are a few fuzzy quantization intervals covering the input domains, the mapping relationship can be very easily expressed by using the IF-THEN formalism. (In some applications this leads to a simpler solution in less designing time.) The overlapping of these fuzzy domains and their usually linear membership functions will eventually allow a rather high-resolution I/O function between crisp input and output variables to be achieved. Mamdani's development of fuzzy controllers in 1974 gave rise to the utilization of these fuzzy controllers in ever-expanding capacities.

To sum it up, fuzzification is the transformation of numerical data from the input to linguistic terms. The knowledge base provides necessary information for all the components of the fuzzy controller. The fuzzy inference engine or the logical decision-making is the core (brain) of the controller. It can simulate the decision-making of human beings. At the end of the inference step, the obtained result is a fuzzy value that cannot be directly used to control the process, so the value should be defuzzied to obtain a crisp value, and that is the role of the defuzzification interface.

STRUCTURE AND ASSUMPTIONS

The Tank was designed with the following parameters :

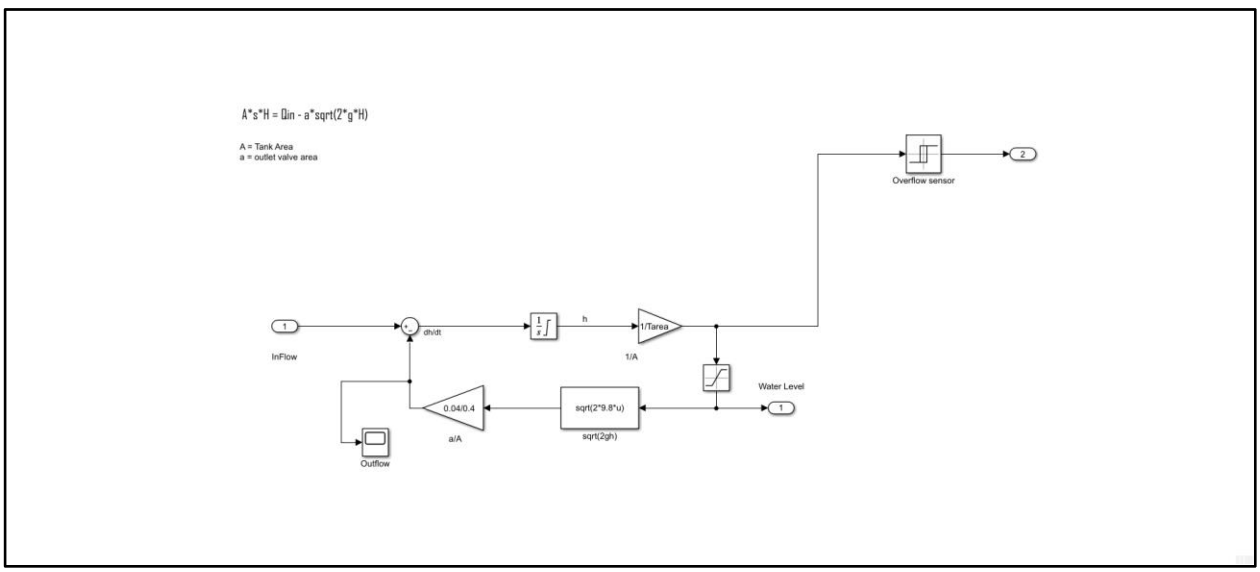
Height	10 m
Tank Base Area	0.4m^2
Outflow Valve Area	0.04m^2
Type	Continuous

The valve was chosen to be such that it integrates the controller output with an added emergency OFF for overflow signals:

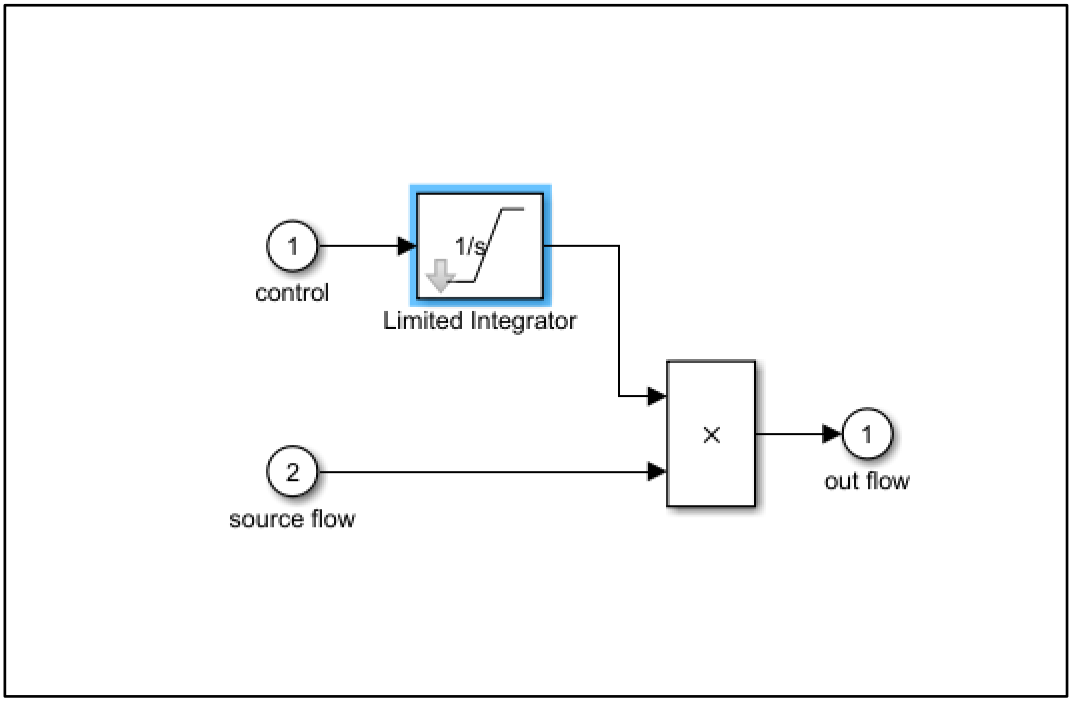
Maximum Valve Flow Rate	2m^3/sec
Valve Type	Integrating

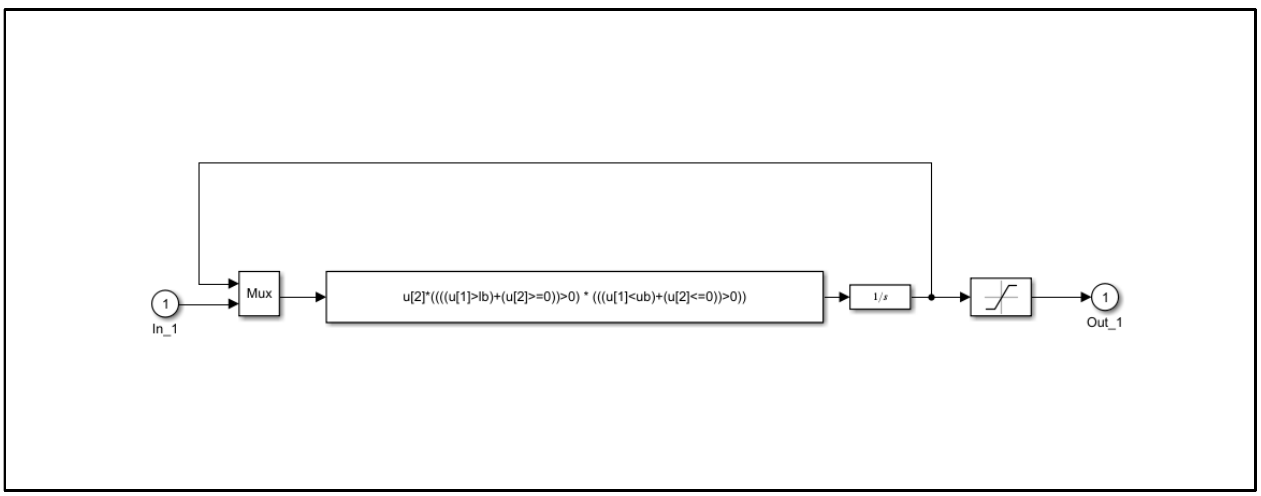
For both the controllers (PID, FLC) we kept these process parameters and final control element variables the same.

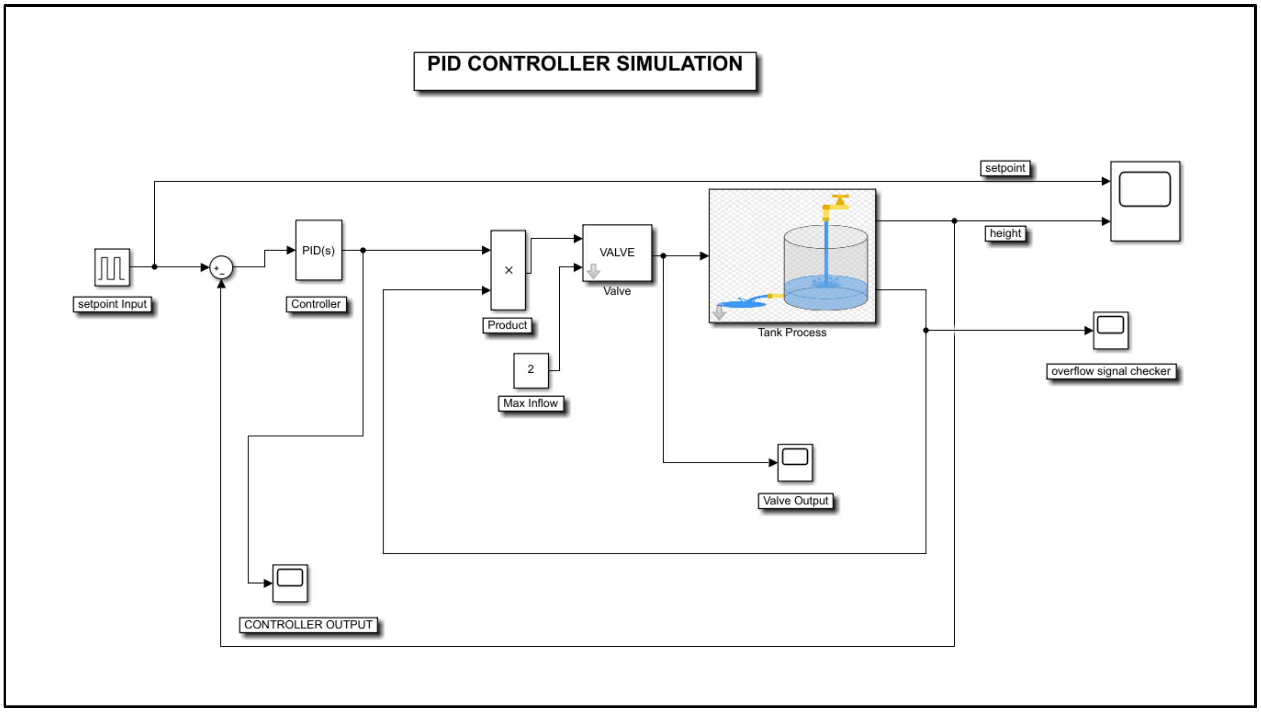
TANK MODELLING:



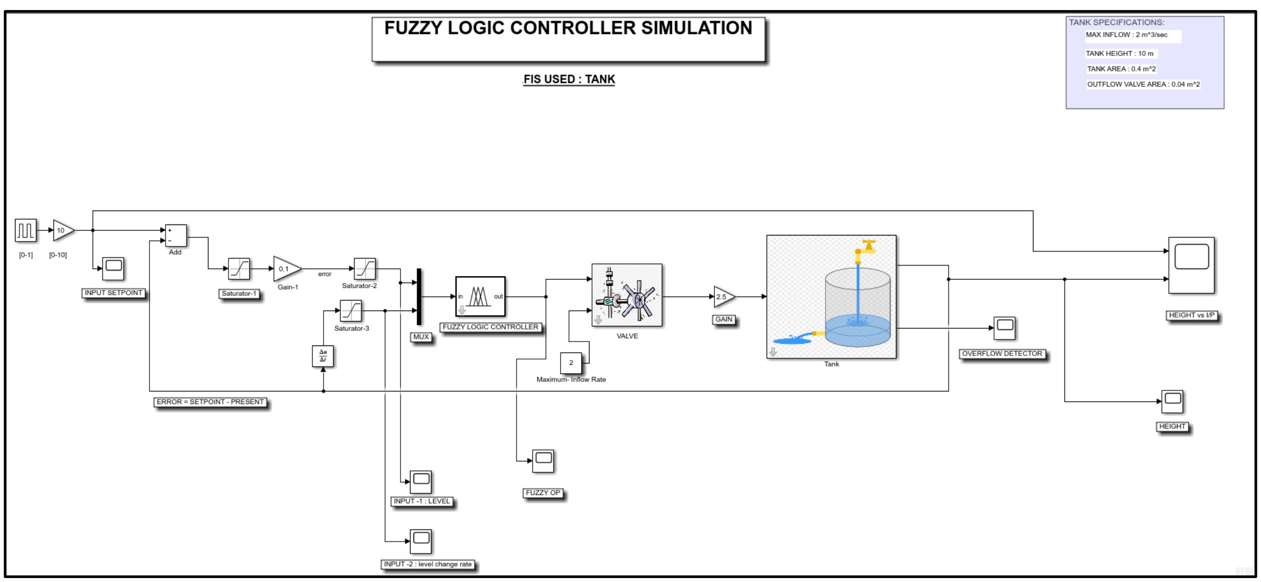
VALVE MODELLING:







PID CONTROLLER SIMULATION
setpoint
height
PID(s)
×
VALVE
setpoint Input
Controller
Valve
Product
Tank Process
2
Max Inflow
overflow signal checker
Valve Output
CONTROLLER OUTPUT



FUZZY LOGIC CONTROLLER SIMULATION
FIS USED : TANK
TANK SPECIFICATIONS:
MAX INFLOW : 2 m^3/sec
TANK HEIGHT : 10 m
TANK AREA : 0.4 m^2
OUTFLOW VALVE AREA : 0.04 m^2
10
[0-1]
[0-10]
Add
INPUT SETPOINT
Saturator-1
0.1
Gain-1
error
Saturator-2
Saturator-3
MUX
in
out
FUZZY LOGIC CONTROLLER
VALVE
2
Maximum- Inflow Rate
2.5
GAIN
Tank
OVERFLOW DETECTOR
HEIGHT vs I/P
HEIGHT
ERROR = SETPOINT - PRESENT
FUZZY OP
INPUT -1 : LEVEL
INPUT -2 : level change rate

The General Structure Of Controllers:

This Signal coming out of both the controllers is then fed to the valve which integrates and scales the controller signal to allow the inflow of water in the tank.

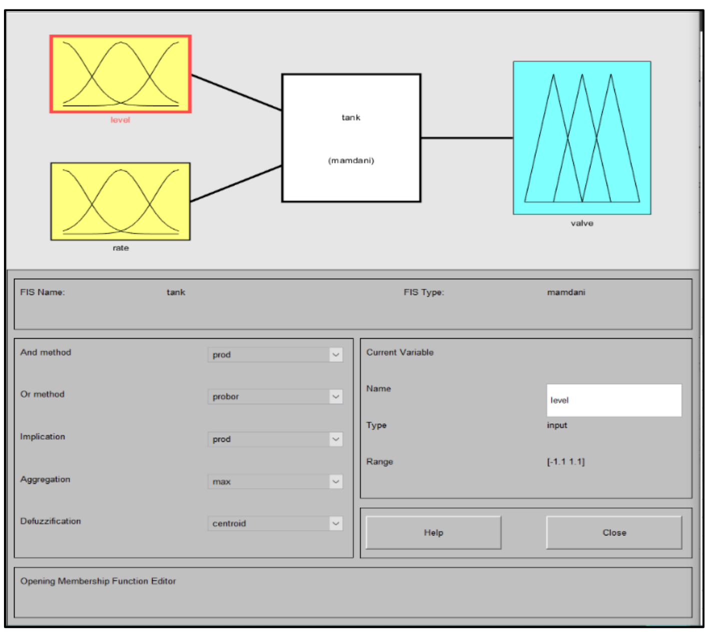
The outflow valve is unregulated and thus the outflow rate can't be controlled by us, it will depend on the plant parameters like outflow valve area and tank base area.

FUZZY LOGIC CONTROLLER:

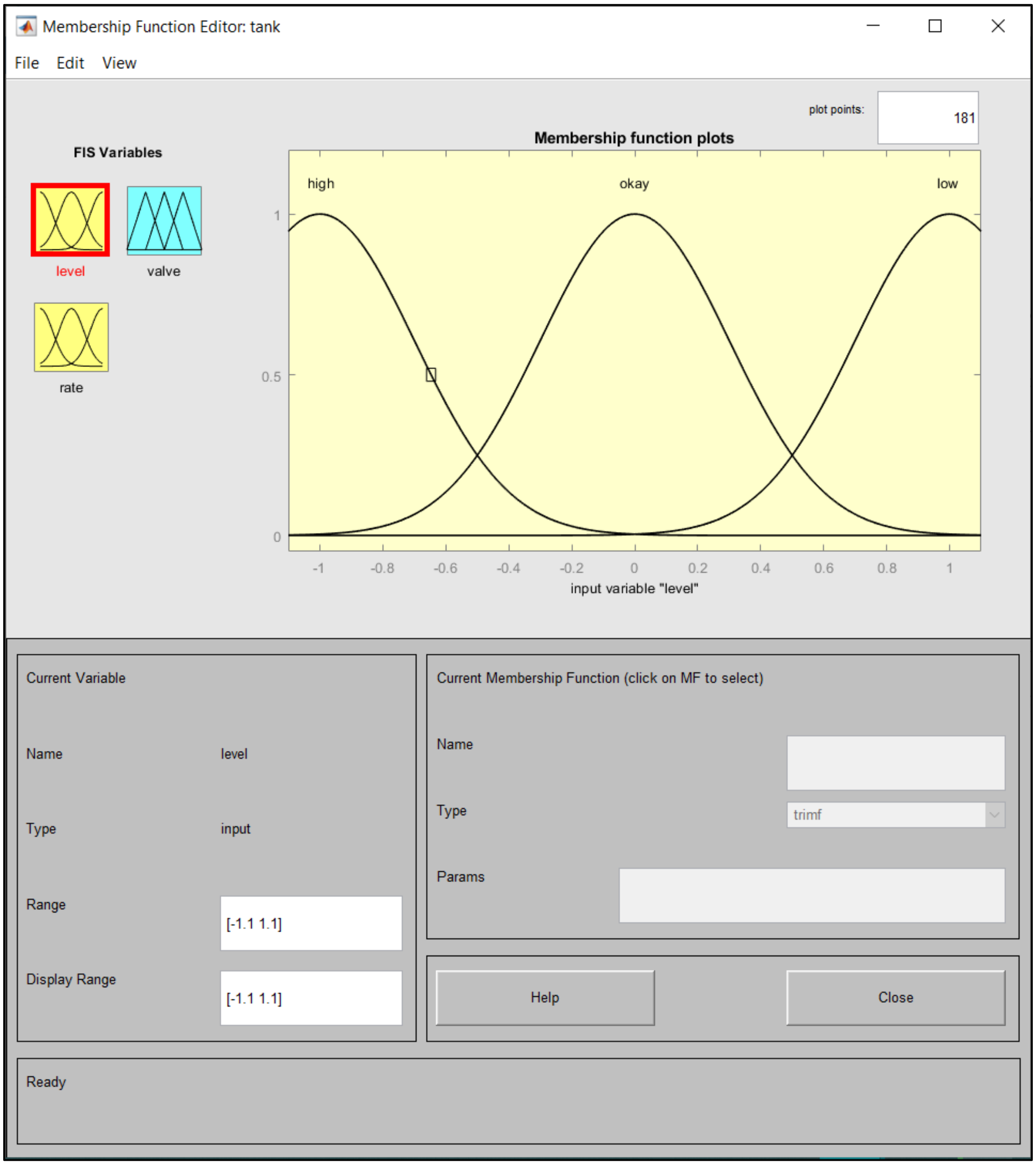
FIS TYPE: Mamdani
AND Method: PRODUCT
OR Method: PROBOR
IMPLICATION: PROD
AGGREGATION: MAX
DEFUZZIFICATION: CENTROID

No. Of Inputs: 2 No. Of Outputs: 1

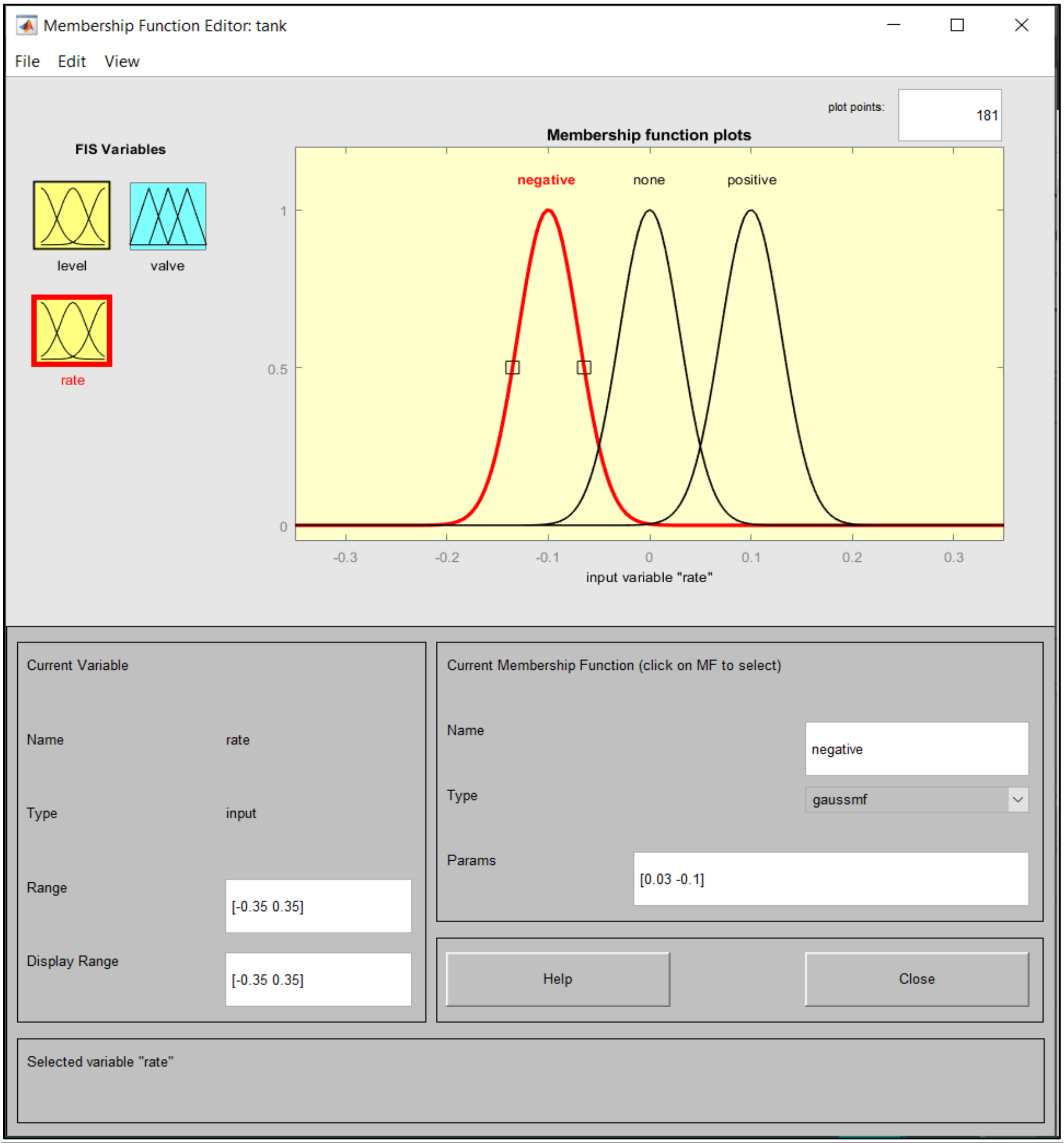
***Input* – 1: Error in Level of Water**
***Range*: [-1.1,1.1]**
***Input* – 2: Rate of change of level of water in tank**
***Range:* [-0.35,0.35]**
***Output* – 1: Controller signal [-1.1,1.1]**



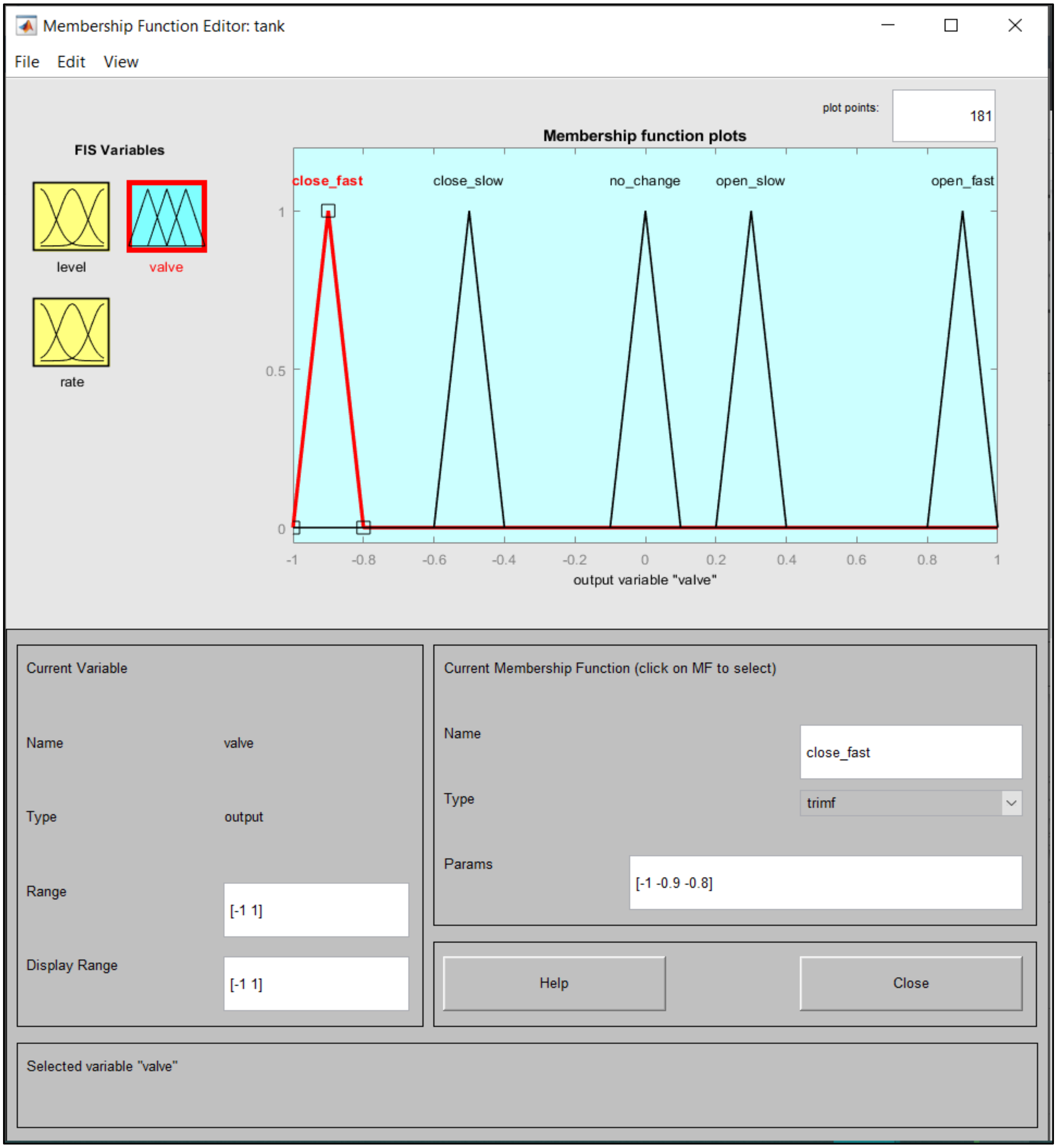
The Membership Functions:



The membership functions and ranges are given for INPUT-1: (Error in Level of Water)
3 Fuzzy Variables
Gaussmf – High, Okay, Low
[0.3 -1] – High
[0.3 0] – Okay
[0.3 1] - Low

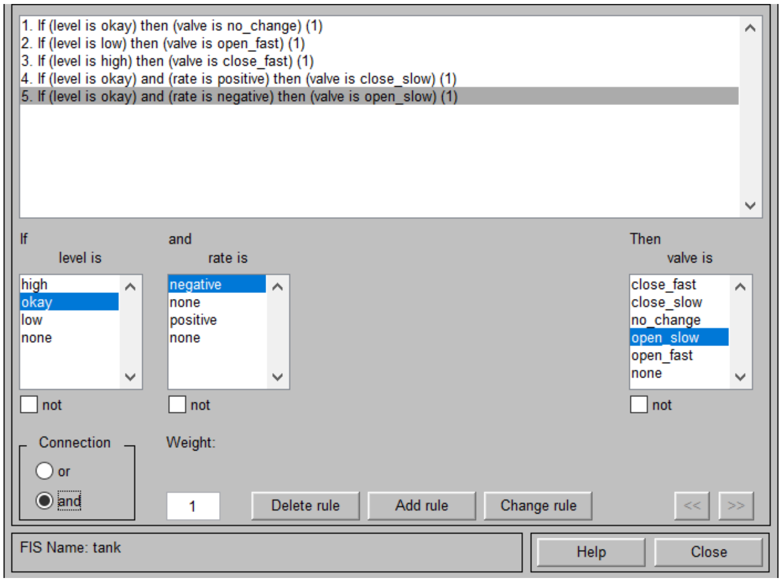


<u>The membership functions and ranges are given for INPUT-2 : (</u>Rate of change of level of water in tank)
3 Fuzzy Variables
<u>Gaussmf-</u> Negative, none, Positive
Negative : [0.03 -0.1]
None : [0.03 0]
Positive : [0.03 0.1]

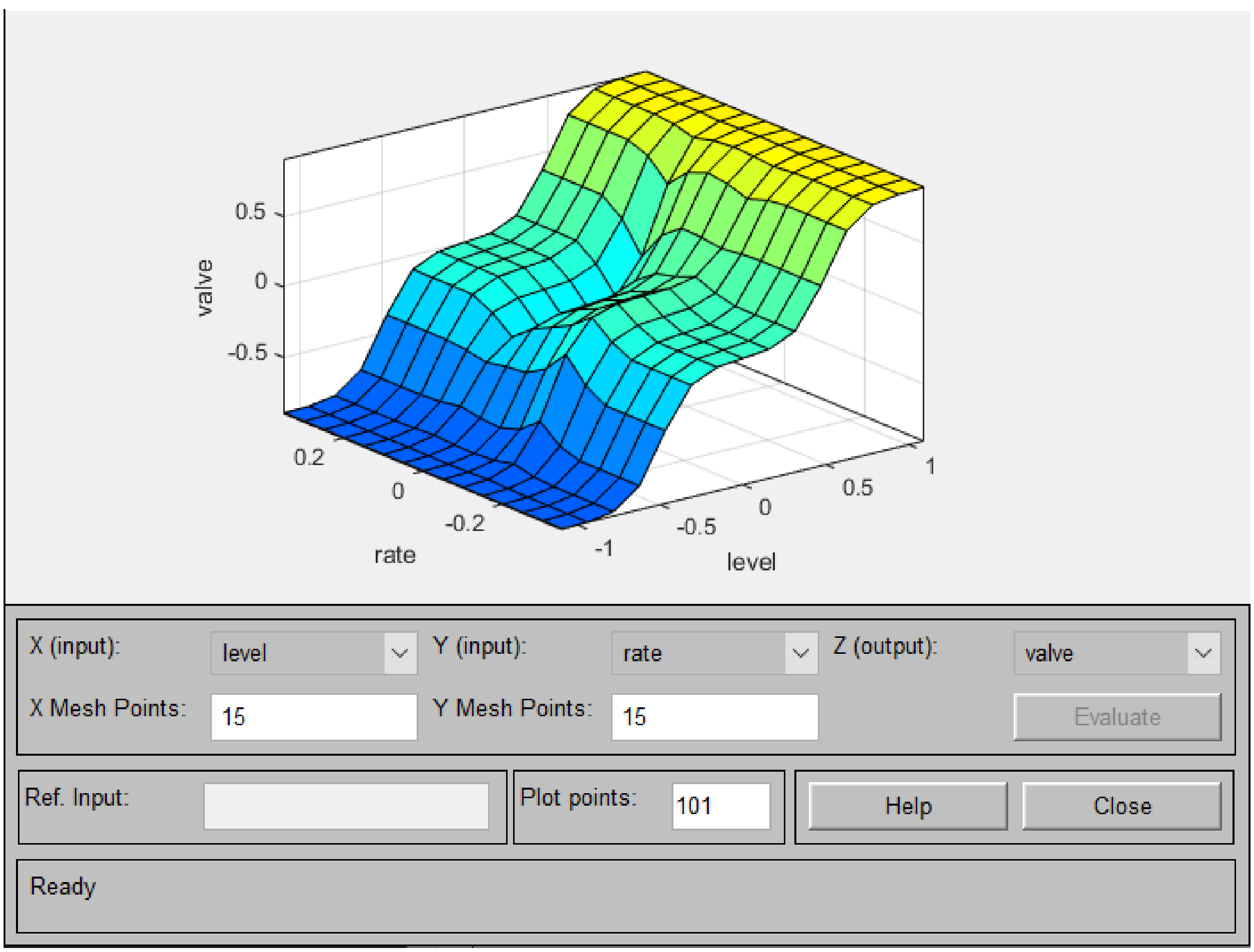


<u>The membership function and ranges are given for OUTPUT.</u>
<u>5 Fuzzy Variables</u>
<u>Trimf-</u> close_fast, close_slow, no_change, open_slow, open_fast
Close_fast: [-1 -0.9 -0.8]
Close_slow: [-0.6 -0.5 -0.4]
No_change: [-0.1 0 0.1]
Open_slow: [0.2 0.3 0.4]
Open_fast: [0.8 0.9 1]

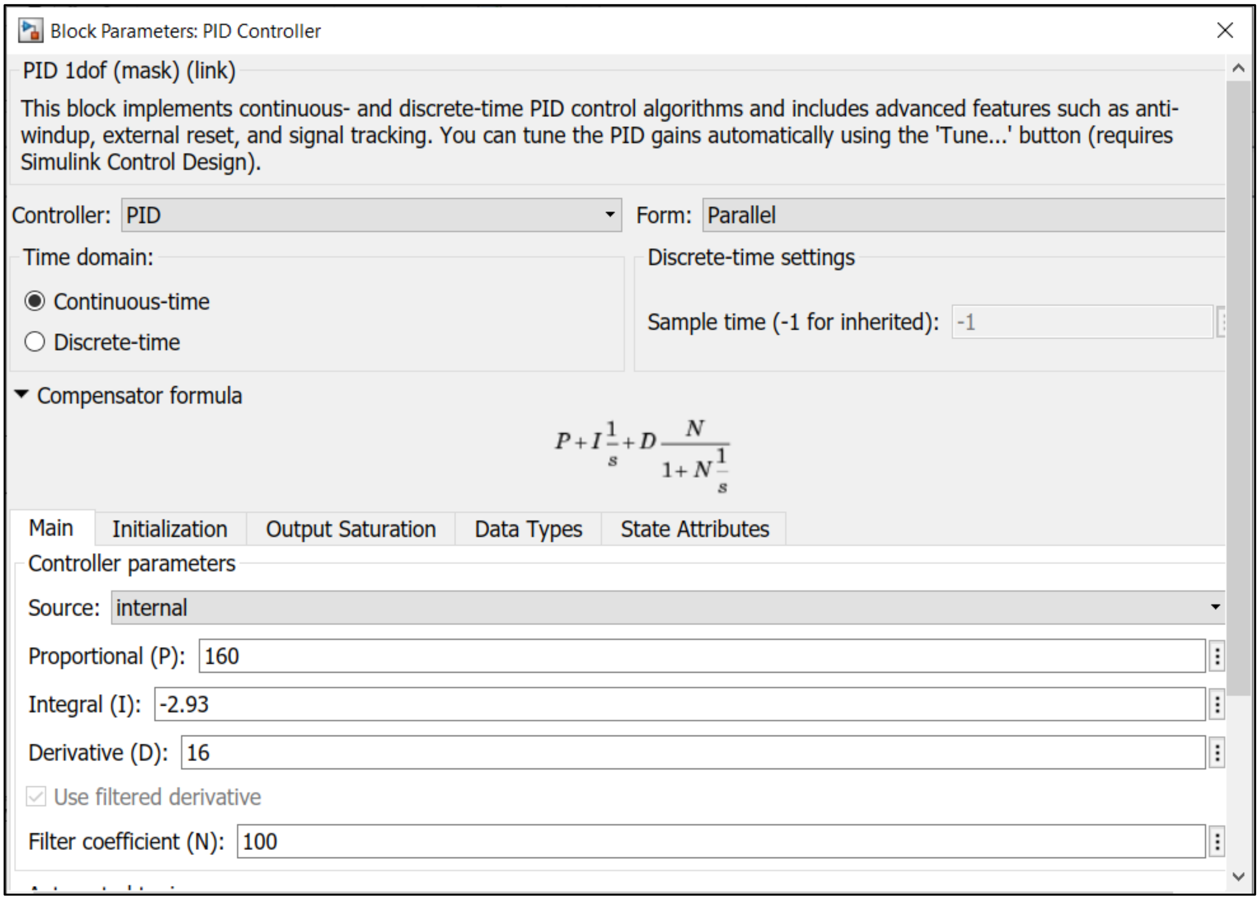
The Fuzzy Rules Used:



The Fuzzy Rules Used When depicted as a Surface:



PID CONTROLLER:



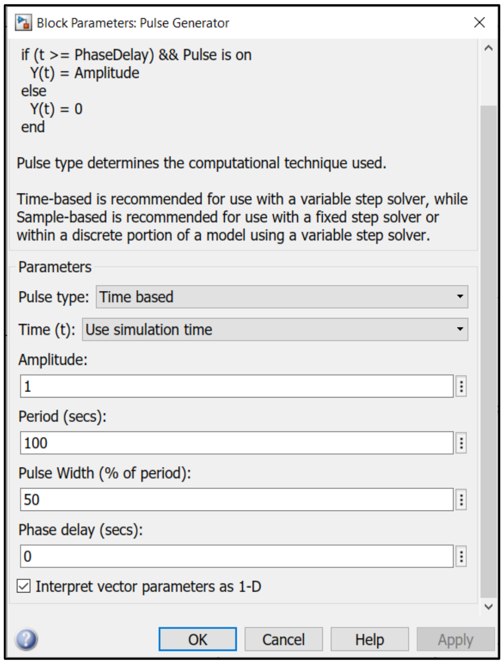
<u>Proportional Gain:</u> 160
<u>Integral Gain</u>: -2.93
<u>Derivative Gain:</u> 16
Parallel PID used

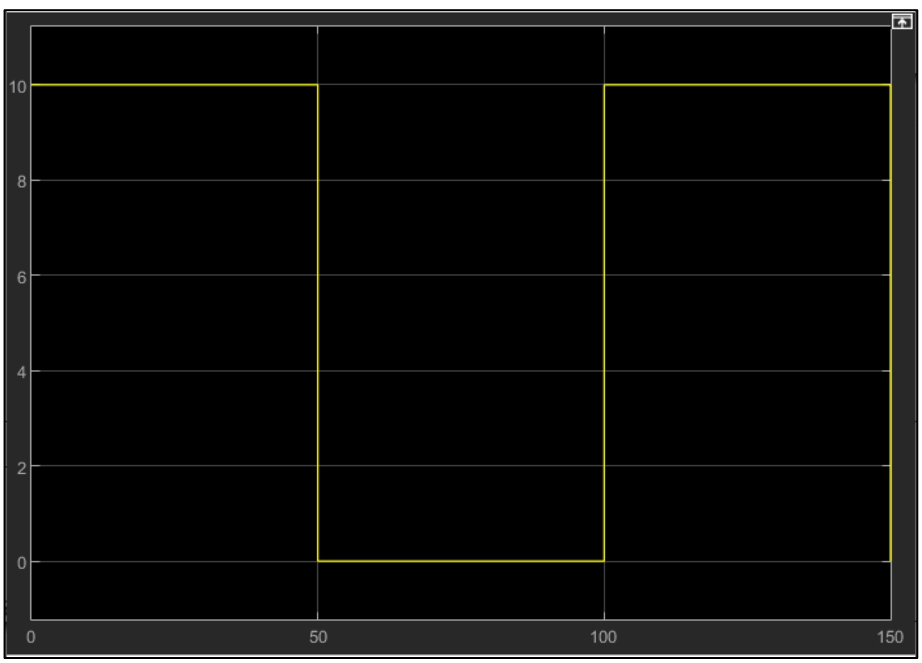
Similar to the Fuzzy Logic Controller this also gives the control signal to a valve that integrates the signal and scales it. Thus, regulating the inflow of water in the tank.

The outflow valve is unregulated and thus the outflow rate can’t be controlled by us, it will depend on the plant parameters like outflow valve area and tank base area.

SIMULATION RESULTS:

PID Controller: The input setpoint was given as the pulse of period 100 sec and 50% duty cycle

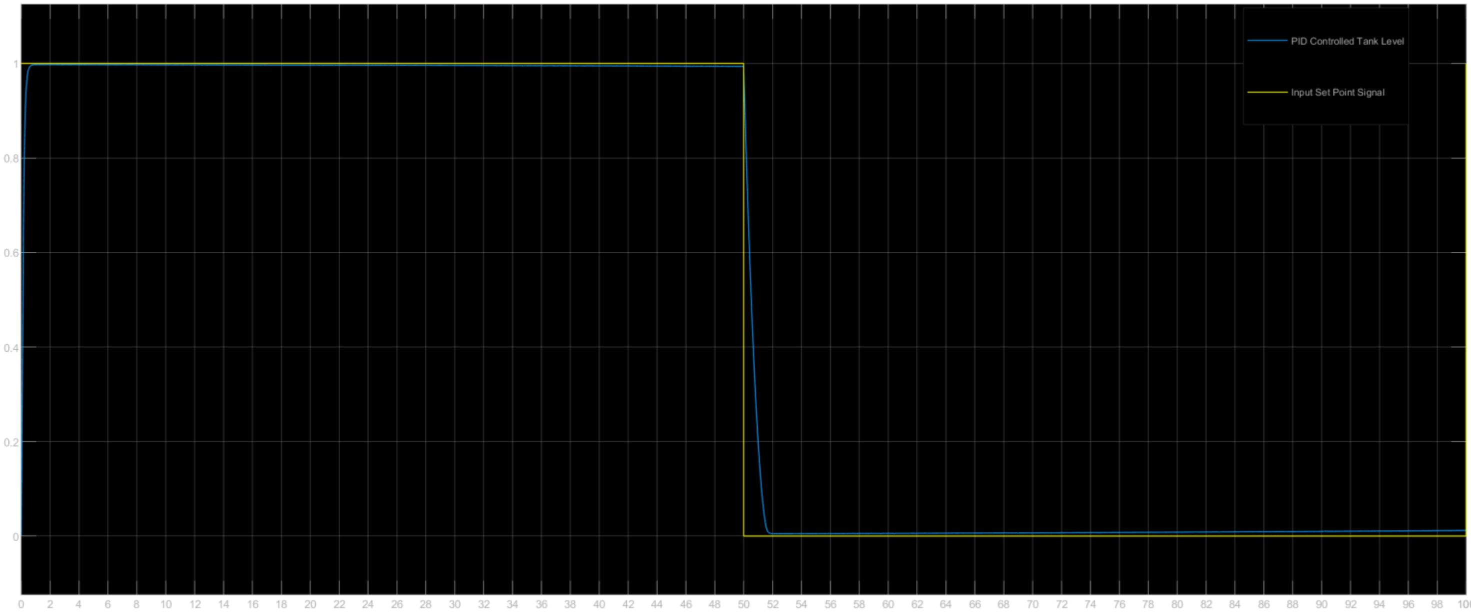




GRAPHS:

The graph of height vs Time was obtained as follows.

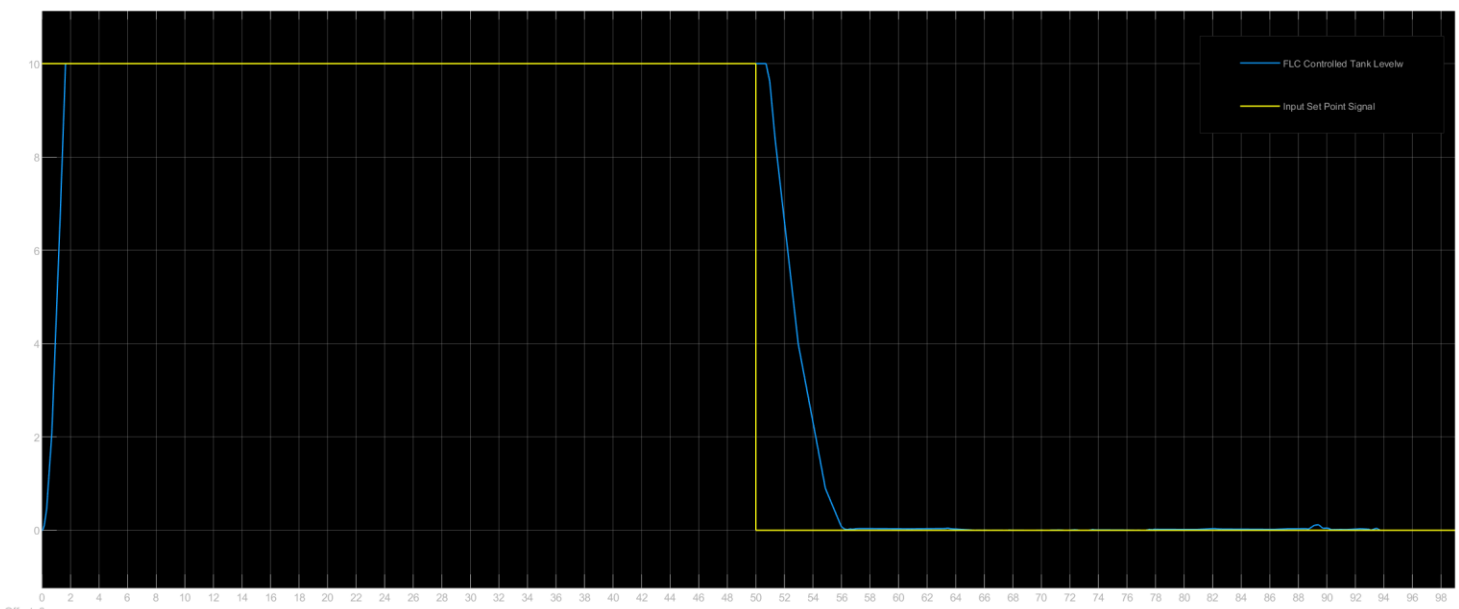
PID CONTROLLER



FUZZY LOGIC CONTROLLER:

The input setpoint was given as the pulse of period 100 sec and 50% duty cycle

The graph of Height vs Setpoint signal was obtained as follows:



Observations

From looking at the responses of both the controllers we concluded the following points:

Parameter	PID	FLC
Overshoot	More	Less
Settling Time	More	Less
Transient	Present	Not Present
Rise Time	Less	More

As we can see, it is clear that fuzzy logic has better stability, small overshoot and is having the fast response as compared to conventional PID Controller. Hence, it is recommended option for controlling fluid levels.

Inferences and Comments:

Fuzzy logic controller is thus conceived as a good solution for constant water level controlling application. 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 Fuzzy Logic Control 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 liquid level tracking applications.

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