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Problem statement

1.1 Problem at Hand

The given system should have a constant flow of temperature and continuous flow rate, so the temperature in the reactor remains the same. We must design a mechanism that will fulfill all these tasks.

1.2 Requirement

The parameter that we are going to control are as follow:

- Level
- Temperature
- Valve opening (F1)
- Steam valve

The control we are going to implement is **relaxed control**.

1.3 Economic and safety features

1.3.1 Economic features

1.3.1.1 Venting

It is possible to keep the exhaust from your water heater outside of your home if you properly vent it. A wide range of sizes and shapes are available for ventilation configurations, each designed to meet a particular requirement. Before the installation, you should have a qualified plumber inspect the ventilation system in your home. After the inspection, the plumber will make recommendations tailored to your requirements.

1.3.1.2 Glass Lined tank

Over eight decades ago, A. O. Smith was the first company to begin commercial production of glass-lined tanks for tank water heaters. These tanks were intended for use in tank water heaters. The interior of the tank has been lined with glass to prevent the exterior steel from rusting and becoming a safety hazard. It was done for obvious reasons. This action was taken to maintain the structure of the tank.

1.3.1.3 Temperature and pressure relief valve

The T&P valve may open and let out both the pressure and the hot water if the water temperature goes above the nominal temperature or if the pressure goes above the nominal pressure. Due to the water's expansion because of being heated, the pressure inside the tank increases when it is heated. We strongly suggest making use of an expansion tank to keep the pressure inside the tank at a healthy level. In the absence of an expansion tank, the surplus of water will be unable to find a place to go, which will lead to an increase in pressure throughout the system. If the T&P valve springs a leak, this may suggest that the temperature or pressure settings are not accurate. If this takes place for you, you should not hesitate to get in touch with an experienced plumber.

1.3.2 Economic features

- It must be in an isolated location far from any populated areas.
- The disposal of its waste requires careful attention.
- Because of this, it should not have a negative impact on the environment.

Modelling and Block diagrams

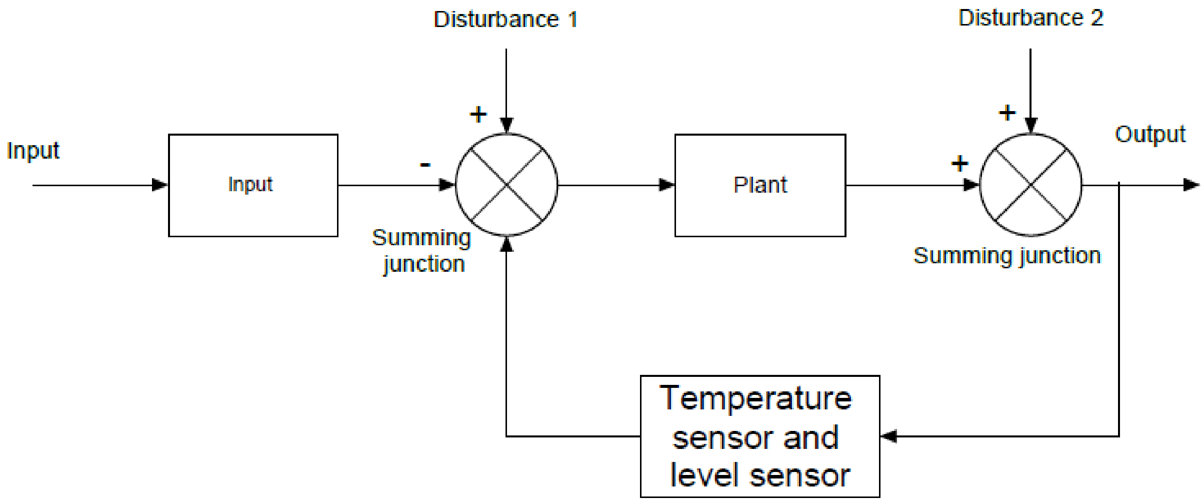

Figure 1 Open-loop block diagram

2.1 Mathematical modelling

A mathematical model will typically describe a system by employing a group of variables and a group of equations that establish the relationships between those groups of variables. It is how mathematical models work. The values of variables can be of any data type, such as strings, Boolean values, real or integer numbers, etc. Variables represent different aspects of the system, such as the system's measured outputs, which are typically in the form of signals, as well as timing data, counters, and the occurrence of events. Variables can also be used to keep track of the number of times something has happened. The actual model is made up of a collection of functions, each of which explains one of how the variables are related to one another.

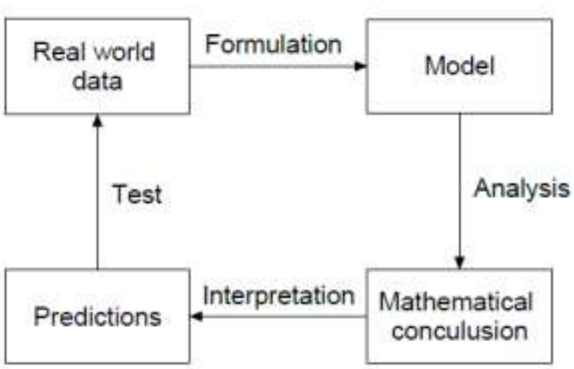

Figure 2 Mathematical modelling block diagram

2.1.1 First order transfer function

The convenient representation of the linear dynamic system. The single-order transfer function represents the one-to-one relationship between an input and an output. The terminology described here will be used

- X in the input, which is here to cause
- Y is the output which is here to effect generally known as output response

Assume the constant liquid hold-up and flow rates are as follows

$$V\rho c\frac{dT}{dt} = wC(T_i - T) + Q \ldots\ldots\ldots\ldots (1)$$

Suppose the process is initially at a steady-state condition, then

$$T\ (0) = \overline{T},\ T_i(0) = \overline{T}_i$$

$$Q\ (0) = \overline{Q} \ldots\ldots\ldots\ldots (2)$$

Where $\overline{T} \equiv$ steady-state value of T, etc. For steady-state conditions

$$0 = wC(T_i - T) + Q \ldots\ldots\ldots\ldots (3)$$

By subtracting the following equations, we get

$$V\rho c\frac{dT}{dt} = wC[(T_i - \overline{T}_i) - (T - \overline{T})] + Q\text{-}\overline{Q} \ldots\ldots\ldots\ldots (4)$$

But here,

$$\frac{dT}{dt} = \frac{d(T-\overline{T})}{dt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$\overline{T}$ is constant, so we can substitute (4 into the 2nd equation) to get,

$$V\rho c\frac{dT'}{dt} = wC[(T_i{}' - T')] + Q' \ldots\ldots\ldots\ldots\ldots (6)$$

Here is the introduction of the single derivative variable, which is also known as the first derivative variable, which is also known as perturbation variables

$$T' \equiv T - \overline{T} \ldots\ldots\ldots\ldots\ldots (7)$$

$$T_i' \equiv T_i - \overline{T}_i \ldots\ldots\ldots\ldots\ldots (8)$$

$$Q' \equiv Q - \overline{Q} \ldots\ldots\ldots\ldots\ldots (9)$$

Taking the Laplace transformation on both sides of the equations, we get

$$V\rho c = sT'(s) - T'(t=0) = wc[(T_i'(s) - T'(s)] + Q'(s) \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Now evaluating the time T′ (t=0). We get

$$T'(0) = T(0) - \overline{T} \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

But in the start, we assumed our starting initial condition was that process was initiated at a steady-state, i.e., T (0) = $\overline{T}$ which follows from equation number 9, which is $T'(0) = 0$

But here, the one more important thing is that the advantage of using deviation variables is that the initial condition term becomes zero.

Now rearranging the equation number 8 to solve for the T' (s)

$$T'(s) = \left(\frac{Ks}{\tau s+1}\right) Q'(s) + \left(\frac{1}{\tau s+1}\right) T_i'(s) \ldots\ldots\ldots\ldots\ldots (12)$$

Now here, two new symbols are defined

$$K \triangleq \frac{1}{wc} \text{ and } \tau \triangleq \frac{V\rho}{w} \ldots\ldots\ldots\ldots (13)$$

So, the first-order transfer function will have occurred when supposing the T_i is constant at a steady-state value. Thus, T_i (t) = $\overline{T}_i$ (t) = 0 ⇒ $\overline{T}_i' = 0$. Then we can substitute into the equation number 12 and rearrange it to get the desired transfer function which is

$$\boldsymbol{\frac{T_i'(s)}{Q'(s)} = \frac{K}{\tau s+1} \ldots\ldots\ldots\ldots (14)}$$

$$\text{Rate Accumulation} = (\text{Flow in}) - (\text{Flow out}) - (\text{Rate Generation})$$

$$\text{Rate Accumulation} = Q_i\rho - Q_o\rho \ldots\ldots\ldots\ldots\ldots (1)$$

$$\frac{dV}{dt} = Q_i\rho - Q_o\rho$$

$$\text{Assume } \frac{dV}{dt} = 0$$

$$Q_i = Q_o$$

$$T_1\ (t) = T\ (t\text{-}\theta)\ \partial\ (t-0)$$

Taking the Laplace

$$T(s) = \frac{\mathbf{K}}{\boldsymbol{\tau}\mathbf{s}+\mathbf{1}}\ (Q(s))$$

$$T_1\ (s) = \frac{KM}{s(\boldsymbol{\tau}\mathbf{s}+\mathbf{1})} e^{-\theta s}$$

Taking the Laplace inverse

$$\text{Deadbeat} = KM\ (1 - e^{-\frac{t-\theta}{\tau}} \delta(t-\vartheta)$$

2.1.2 Energy balance

$$\text{Accumulation} = \text{in by flow} + \text{in by heat flow} - \text{out by flow}$$

$$\frac{dV\rho c(T_{out} - T_{ref})}{dt} = F_{out}\rho_{out}c_{out}\left[\left(T_{out(i)} - T_{ref}\right) - (T_{out} - T_{ref})\right] - Q \ldots\ldots\ldots\ldots (2)$$

Now T_{ref} is constant

$$\frac{d(T_{out})}{dt} = \frac{F_{out}}{V_{out}}\left(T_{out(i)} - T_{ref}\right) - \frac{Q}{V_{out}\rho_{out}c_{out}} \ldots\ldots\ldots\ldots\ldots (3)$$

$$Q = UA(T_{out} - T)$$

Subtitling Q into the model to balance the energy

$$\frac{d(T_{out})}{dt} = \frac{F_{out}}{V_{out}}\left(T_{out(i)} - T_{ref}\right) - \frac{Q = UA(T_{out} - T)}{V_{out}\rho_{out}c_{out}} \ldots\ldots\ldots\ldots\ldots (4)$$

2.2 State space

$$\frac{dx}{dy} = Ax + Bu$$

$$y = Cx + Du$$

$$x = \begin{bmatrix} T & -Tref \\ Tout & Toutref \end{bmatrix} \ldots\ldots\ldots\ldots\ldots \text{State variables}$$

$$x = \begin{bmatrix} F_{out} & -F_{outref} \\ F & F_{ref} \\ T_{Ini} & T_{out} \\ T_{out} & T_{outIni} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots \text{Input variables}$$

$$y = \begin{bmatrix} T & -Tref \\ Tout & Toutref \end{bmatrix} \ldots\ldots\ldots\ldots\ldots \text{Output variables}$$

For elements of matrix A

$$A_{ij} = \frac{\partial f_i}{\partial x_{out}}$$

$$A_{11} = \frac{UA}{V\rho c} \ldots\ldots\ldots (5)$$

$$A_{12} = \frac{UA}{V\rho c} \ldots\ldots\ldots (6)$$

$$A_{21} = \frac{UA}{V_{out}\rho_{out}c} \ldots\ldots\ldots (7)$$

$$A_{22} = -\frac{F_{outref}}{F_{out}} - \frac{UA}{V_{out}\rho_{out}c} \ldots\ldots\ldots (8)$$

For elements of matrix B

$$B_{ij} = \frac{\partial f_{ini}}{\partial u_{out}}$$

$$B_{11} = \frac{\partial f_{ini}}{\partial (F_{out} - F_{outref})} \ldots\ldots\ldots (9)$$

$$B_{12} = \frac{T_{refout} - T_{ref}}{V} \ldots\ldots\ldots (10)$$

$$B_{13} = \frac{F_{out}}{V} \ldots\ldots\ldots (11)$$

$$B_{14} = \frac{\partial f_i}{\partial T_{outini}} \ldots\ldots\ldots (12)$$

$$B_{21} = \frac{T_{refoutini} - T_{outref}}{V_{out}} \ldots\ldots\ldots\ldots (13)$$

$$B_{22} = \frac{\partial f_2}{\partial F} \ldots\ldots\ldots\ldots (14)$$

$$B_{22} = \frac{\partial f_2}{\partial T_{ini}} \ldots\ldots\ldots\ldots (15)$$

$$B_{22} = \frac{\partial F_{outref}}{V_{out}} \ldots\ldots\ldots\ldots (14)$$

Since both states are known and put the values from the question into the equations as mentioned earlier

$$A = \begin{bmatrix} -0.4 & 0.3 \\ 3 & -4.5 \end{bmatrix}$$

$$B = \begin{bmatrix} -0.4 & -7.5 & 0.1 & 0 \\ 50 & 0 & 0 & 1.5 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

2.3 Laplace Domain model

$$\mathrm{Y(s)} \ = \ \mathrm{G(s)} \times \ \mathrm{U(s)}$$

$$\mathrm{G(s)} \ = \ \mathrm{C(sI - A)^{-1} \times B}$$

$$\mathrm{G(s)} = \frac{\begin{bmatrix} 15 & (-7.5s - 33.75) & (0.1s + 0.45) & 0.45 \\ (50s + 20) & -22.5 & 0.3 & (1.5s + 0.6) \end{bmatrix}}{s^2 + 4.9s + 0.9}$$

$$\text{The poles are } -0.191 \text{ and } -4.709$$

$$\mathrm{g11(s)} = \frac{15}{s^2 + 4.9s + 0.9}$$

$$\text{By dividing the whole equation by 0.9, we get}$$

For process 1

$$\mathbf{g11(s)} = \frac{\mathbf{16.6667}}{\mathbf{1.111s^2 + 5.444s + 1}}$$

For process 2

$$\mathrm{g21(s)} = \frac{50s + 20}{s^2 + 4.9s + 0.9}$$

$$\text{By dividing the whole equation by 0.9, we get}$$

$$\mathbf{g21(s)} = \frac{\mathbf{22.22(2.5s + 1)}}{\mathbf{(0.21236s + 1)(5.23207s + 1)}}$$

Control strategies

In the case of an impact system, the presence of a particular mathematical relationship between the system's input and output defines the system's nature. The term "linear proportionality" refers to the mathematical representation of the relationship between the inputs and outputs of a linear system. It is said that a system is nonlinear when the relationship between the input and the output cannot be described using a single linear proportionality—this points to the fact that there is a nonlinear relationship between the input and the output.

3.1 Types of control systems

There are different types of control systems, but they are all designed to keep costs under control. A system manages position, speed, acceleration, temperature, pressure, voltage, current, etc. An example of an operating system. To clarify the concept, let's take an example of a simple room thermostat. Imagine a specific heating element that can only generate heat when it is physically connected to a power source. When the power switch on the heater is turned on, the temperature in the room rises briefly before returning to the level that was previously set. If the desired temperature is always maintained inside, the heater will need to be manually turned on whenever the temperature outside drops. You can make manual adjustments to the room's temperature using this feature. One example of something that needs to be operated manually is presented here. If this system had a power timer that activated and deactivated the heating element at predetermined intervals, its performance would be significantly improved. It would make it much simpler to maintain the appropriate temperature throughout the space. Another cutting-edge method for regulating the temperature is applicable in any setting. The difference between the actual and desired temperature can be determined with the help of a sensor. If there is a temperature difference, the heater will work to bring it down until it reaches a set point, at which point it will turn off. If there is no difference in temperature, the heater will not work. Both systems are entirely computerized and managed by automated software and hardware. What goes into the system does not affect what comes out of it. The room temperature (or the plug, depending on where you are) will increase when the power is turned on. When the switch is turned to the "on" position, the heater radiates heat throughout the space.

On the other hand, the absolute temperature does not affect the amount of power delivered to the system. An open-loop system is the name of this computer operating system. In the second scenario, the heating element of the system operates based on the difference between the actual temperature and the temperature desired for the system. A "system failure" is what statisticians refer to when they see a difference of this nature. The system that oversees the input control is the one that detects and interprets this error signal. This variety of operating systems is known by its technical name, a closed-loop system. The reason for this is that the error feedback from the input paths and the output paths together form a closed loop.

3.2 Cascade control:

When there are multiple measurements but just one control variable, cascade control is used. The variable controlling the process output temperature is the steam flow rate, not the valve opening. Because both valve opening and steam pressure determine the steam flow rate, a flow controller is utilized to maintain the steam flow rate despite variations in steam pressure. In a cascade, the flow controller gets its setpoint from the temperature controller [2].

Cascade control is often used to control slow operations governed by fast processes. Cascade control works best when a process interruption is detected. As a result, cascade control improves the ability to handle changes in steam pressure without affecting feed rate or temperature. The complexity of cascading control is also a disadvantage of additional measuring instruments and controllers. Good performance justifies investing when the internal cycle is more than three times faster than the external cycle. In terms of how it is assembled, cascade control technology is distinct from other forms of control in several important respects. The first stage of the process is the vapour pressure stage, also called the "decomposition" stage. It can be used quickly and provides accurate measurements with little effort. When using the cascade control method, the output of the first Controller communicates with the second Controller, which has a feedback loop and tells it where to begin. As a result of the development of this technology, power outages can now be resolved in a shorter amount of time. In a system that only has one point of control, the level sensor is what provides the user with access to that control point. It allows the individual to control how quickly or slowly they pour liquid into the container. Because of how large the middle is, it takes significantly longer to bring the ship to a level position. The course of events could also shift dramatically in a short amount of time. Therefore, if something changes the flow rate into the system, it might take a very long time for the level to change sufficiently to start making the necessary corrections. It is the case because the level is determined by the volume of water that is being introduced. The level sensor in a cascade system that regulates fluid flow provides feedback to the outer loop controller, which in turn serves as a reference input for the second Controller. Because there is only one control system, flow level circuits can react quickly to changes in flow. Because of this, the differences between the levels are significantly reduced in magnitude.

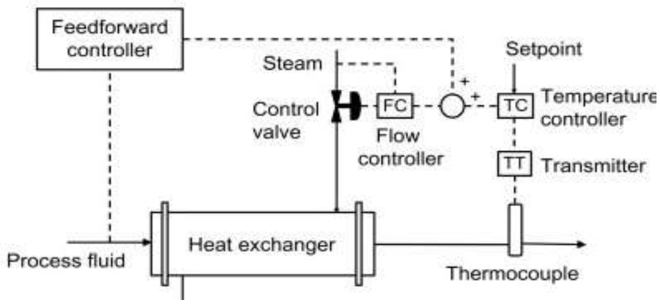

Figure 3 Cascade Control

3.3 Single loop control

Single loop controllers are devices that control a single temperature or process variable. These controllers are relatively inexpensive and simple to operate. Single loop controllers come in various forms, ranging from straightforward virtual instruments to complex variants that include many additional features. These controllers can be utilized to exert fine-grained control over various software programs. Single loop controllers are typically located on the front of the panel most of the time. Many of our controllers come equipped with simple displays to read, allowing you to discern critical pieces of process information and warning signals immediately. Controlling process variables in a wide variety of applications is possible with the help of a single loop controller. Some examples of these applications include industrial and laboratory ovens, sealers, kilns, food processing, extruder barrel heating, and heat presses [3].

What takes place in a control system with a closed-loop is dependent not only on the output variables but also on the input variables. By incorporating feedback into an open-loop control system, it is possible to transform it into a closed-loop control system.

By causing a change in the output, feedback can prevent interference from occurring from the outside world. As a result, the term "closed control system" is frequently used to refer to an automatic control system. The following diagram illustrates a closed eastward feedback system that receives and transmits feedback in the eastward direction.

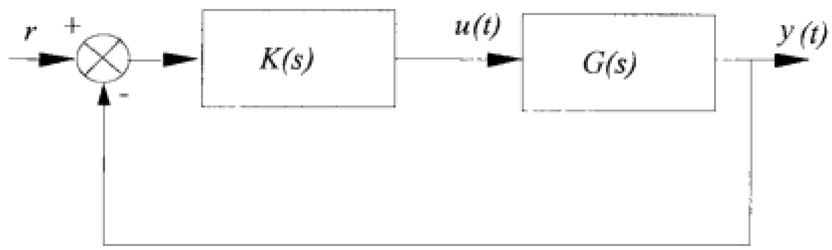

Figure 4 Single loop control

3.3.1 Advantages of single-loop control system

- Closed control systems offer a higher degree of precision, but their operation is not linear
- It has a very high degree of accuracy because if it makes a mistake, a feedback signal will correct it
- Added more bandwidth
- The process of automating things has become less complicated thanks to recent changes
- The level of sensitivity of the system can be dialed down, which will result in the system becoming more stable
- The volume level of this system is likely to be lower.

3.3.2 Disadvantages of single-loop control system

- It is more expensive
- It is more difficult to design
- It requires more upkeep
- It causes responses to go back and forth
- It reduces gross profit.

3.4 Feedforward control:

A part or path that transmits a controlling signal from an external source to an external load is a feedforward component of a control system. This component may also be spelt feedforward. It is also possible to refer to the signal that controls the machine as the feedforward signal. It is an order that usually comes from the outside world.

A feedback system, as opposed to a feedforward system, modifies the input to consider how the load is affected by the input and how the load may change in unexpected ways. It is generally agreed that the load belongs to the system's external environment. [1].

The task is a component of the system's external environment, and the feedback system modifies the input to observe its effect on the task. In addition to this, the task may develop in ways that were not anticipated. On the other hand, forwarding systems adjust their revenue to consider how much load they carry. It is never acceptable to use errors to alter the functioning of a delivery system. Process data, such as a mathematical model of the process and a way to find or measure process failures, are required for it to function correctly and are necessary for it to work at all.

Even if it does not include a feedback control system, a net forward strategy still needs specific characteristics to succeed. An external command or control signal and the appropriate amount of time must be transmitted from the outside to determine how the system's output affects the load (typically, the expected load needs to remain constant). The term "ballistic" refers to the inability to make any adjustments once a control signal has been transmitted in a system that uses forward control without feedback. The most recent control signal must be utilized before making any system adjustments. On the other hand, cruise control uses a feedback system to adjust the cost per the number of passengers in the vehicle.

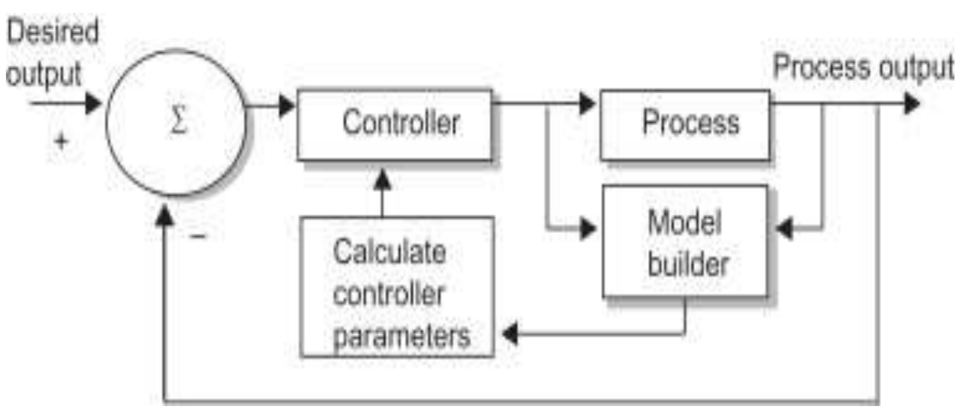

Figure 5 Feedforward control

Features of control

The recommended control is PI control

4.1 PI control

In the PI controller, the actuating signal is directly proportional to the error signal added with the integral of the error signal. It also reduces steady-state error without affecting of stability of the system, especially since K_p is large.

$$u_a(t)\ \alpha\ e(t) + \int e(t)d(t)$$

$$u_a(t) = K_p e(t) + K_I \int e(t)d(t)$$

Taking Laplace on both sides

$$U_a(s) = K_p \times E(s) + \frac{K_I}{s} \times E(s)$$

$$U_a(s) = E(s)\left[K_P + \frac{K_I}{s}\right]$$

$$U_a(s) = E(s)K_P\left[1 + \frac{K_I}{sK_P}\right]$$

$$U_a(s) = E(s)K_P\left[1 + \frac{1}{\tau_I s}\right]$$

$$\text{as } \tau_I = \frac{K_P}{K_I} = \text{Integral Time}$$

$$\text{as } \tau_I = \frac{K_P}{K_I} = \text{Integral Time}$$

$$\frac{U_a(s)}{E(s)} = K_P\left[1 + \frac{1}{\tau_I s}\right]$$

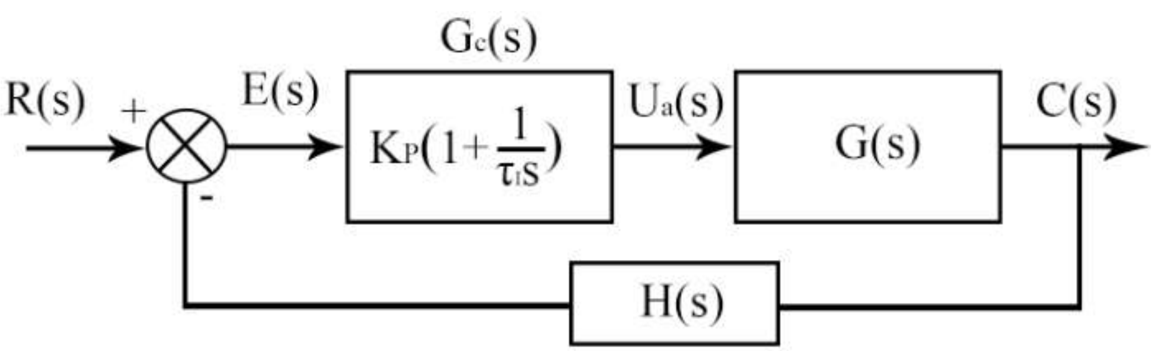

Figure 6 Proportional Integral Controller

4.2 Proportional controller

The signal that tells the system to do something equals the error signal in a proportional controller. It ensures that the system always responds appropriately. The error signal, transmitted via feedback, is the difference between the signals at the input and the signals at the output.

$$\mathbf{u_a(t)\ \alpha\ e(t)}$$

$$\mathbf{u_a(t) = K_p e(t)}$$

Taking laplace on both sides

$$\mathbf{U_a(s) = K_p \times E(s)}$$

$$\mathbf{\frac{U_a(s)}{E(s)} = K_p}$$

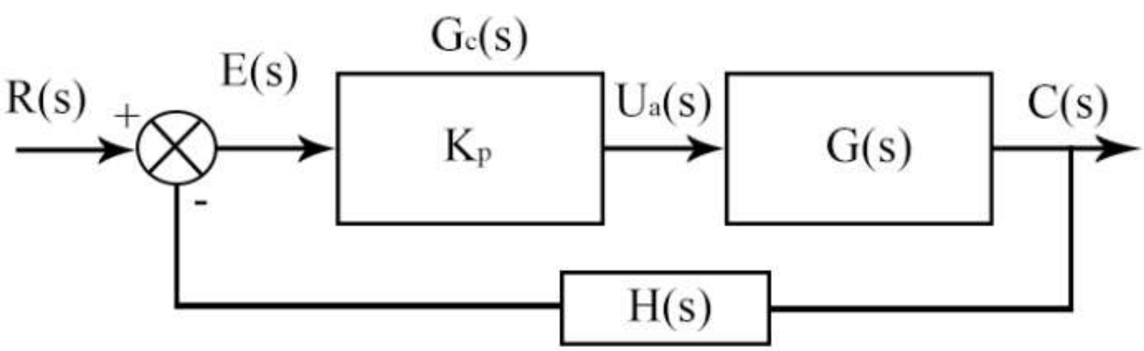

Figure 7 Proportional controller block diagram

4.3 PID controller

The signal that tells the system to do something is directly related to the error signal plus its integration and derivative in a PID controller. This signal tells the system to do something. Controlling a system's stability and the error at a steady state within a predetermined ratio range requires using a PID controller.

$$u_a(t)\ \ \alpha\ \ e(t) + \int e(t)d(t) + \frac{de(t)}{dt}$$

$$u_a(t) = K_p e(t) + K_I \int e(t)d(t) + K_D \frac{de(t)}{dt}$$

Taking Laplace on both sides

$$U_a(s) = K_P \times E(s) + \frac{K_I}{s} \times E(s) + s \times K_D \times E(s)$$

$$U_a(s) = E(s)\left[K_p + \frac{K_I}{s} + s \times K_D\right]$$

$$U_a(s) = E(s)K_p\left[1 + \frac{K_I}{s \times K_p} + \frac{s \times K_D}{K_p}\right]$$

$$U_a(s) = E(s)K_p\left[1 + \frac{1}{\tau_I s} + s\tau_D\right]$$

$$\text{as } \tau_I = \frac{K_P}{K_I} = \text{Integral Time}$$

$$\text{as } \tau_D = \frac{K_D}{K_P} = \text{Delay Time}$$

$$\frac{U_a(s)}{E(s)} = K_p\left[1 + \frac{1}{\tau_I s} + s\tau_D\right]$$

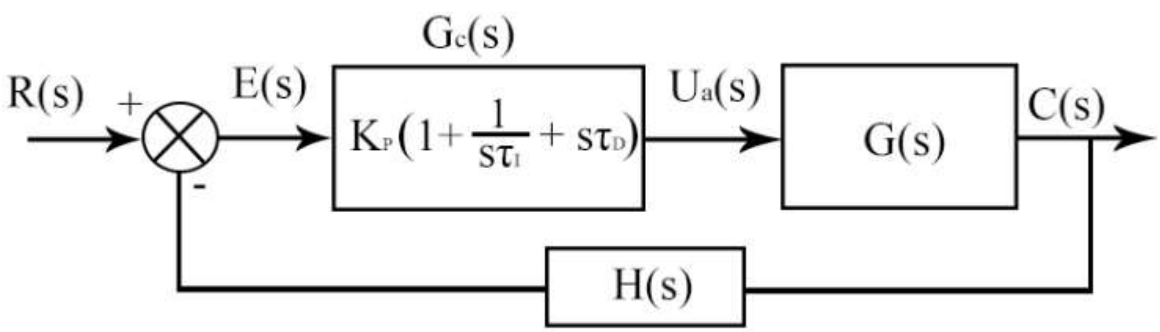

Figure 8 Proportional integral derivative controller

Simulation and Results

5.1 Process transfer function:

$$g11(s) = \frac{16.6667}{1.111s^2 + 5.444s + 1}$$

$$g21(s) = \frac{22.22(2.5s + 1)}{(0.21236s + 1)(5.23207s + 1)}$$

$$G(s) = g11(s) \times g21(s)$$

$$\mathbf{G(s) = \frac{925.85s + 370.333}{1.11\boldsymbol{s}^4 + 12.207\boldsymbol{s}^3 + 31.243\boldsymbol{s}^2 + 10.77\boldsymbol{s} + 1}}$$

5.1.1 For temperature

$$G_{td} = \frac{T(s)}{D(s)}$$

$$\frac{T(s)}{D(s)} = e^{-\tau ds} \frac{K_d}{1 + T_c s}$$

So,

$\tau = \text{time}, d = \text{dsiturbance, which will be in the case is unity and } K_d \text{ gain} = 1\ T = 5 \text{ degree}$

$$\mathbf{\frac{T(s)}{D(s)} = e^{-5s} \times \frac{1}{1 + 5s}}$$

5.1.2 For level

$$\frac{T(s)}{D(s)} = e^{-\tau ds} \times \frac{s + K}{1 + T_c s}$$

$$\mathbf{\frac{T(s)}{D(s)} = e^{-5s} \times \frac{s + 1}{1 + 5s}}$$

5.2 PI tunning

5.1.1 MATLAB Code for PI tunning

```
clc
clear
close all
A=[-0.4 0.3; 3 -4.5];
```

```
B=[-0.4 7.5 0.1 0; 50 0 0 1.5];
C=[0 1; 1 0];
D=0;
% for 1st input the tf of the system is
num1=15;
den1=[1 4.9 0.9];
g1=tf(num1,den1);
% for 2nd input
num2=[50 20];
den2=[1 4.9 0.9];
g2=tf(num2,den2);
plant=g1*g2;
step(plant)
n=[750 300];
d=[1 9.8 25.81 8.82 0.81];
[r p k]=residue(n,d);
% PI control
Kp=3;Ki=0.15;
Control=tf([Kp Ki], [50,0]);
sys_cl=feedback(Control*plant,1);
t=0:0.01:10;
step(sys_cl,t);
s=stepinfo(sys_cl);
sys = zpk([20],[-4.7089 -4.7089 -0.1911 -0.1911],80);
[C_pi,info] = pidtune(sys,'PI')
```

5.2.2 MATLAB Code for P tunning

```
clc
clear
close all
A=[-0.4 0.3; 3 -4.5];
B=[-0.4 7.5 0.1 0; 50 0 0 1.5];
C=[0 1; 1 0];
D=0;
% for 1st input the tf of the system is
```

```
num1=15;
den1=[1 4.9 0.9];
g1=tf(num1,den1);
% for 2nd input
num2=[50 20];
den2=[1 4.9 0.9];
g2=tf(num2,den2);
plant=g1*g2;
step(plant)
n=[750 300];
d=[1 9.8 25.81 8.82 0.81];
[r p k]=residue(n,d);
% PI control
Kp=3;Ki=0.15;
Control=tf([Kp Ki], [50,0]);
sys_cl=feedback(Control*plant,1);
t=0:0.01:10;
step(sys_cl,t);
s=stepinfo(sys_cl);
sys = zpk([20],[-4.7089 -4.7089 -0.1911 -0.1911],80);
[C_p,info] = pidtune(sys,'P')
```

5.2.3 MATLAB Code for PID tunning

```
clc
clear
close all
A=[-0.4 0.3; 3 -4.5];
B=[-0.4 7.5 0.1 0; 50 0 0 1.5];
C=[0 1; 1 0];
D=0;
% for 1st input the tf of the system is
num1=15;
den1=[1 4.9 0.9];
g1=tf(num1,den1);
% for 2nd input
num2=[50 20];
```

```
den2=[1 4.9 0.9];
g2=tf(num2,den2);
plant=g1*g2;
step(plant)
n=[750 300];
d=[1 9.8 25.81 8.82 0.81];
[r p k]=residue(n,d);
% PI control
Kp=3;Ki=0.15;
Control=tf([Kp Ki], [50,0]);
sys_cl=feedback(Control*plant,1);
t=0:0.01:10;
step(sys_cl,t);
s=stepinfo(sys_cl);
sys = zpk([20],[-4.7089 -4.7089 -0.1911 -0.1911],80);
[C_pid,info] = pidtune(sys,'PID')
```

5.2.4 Output Response after tunning

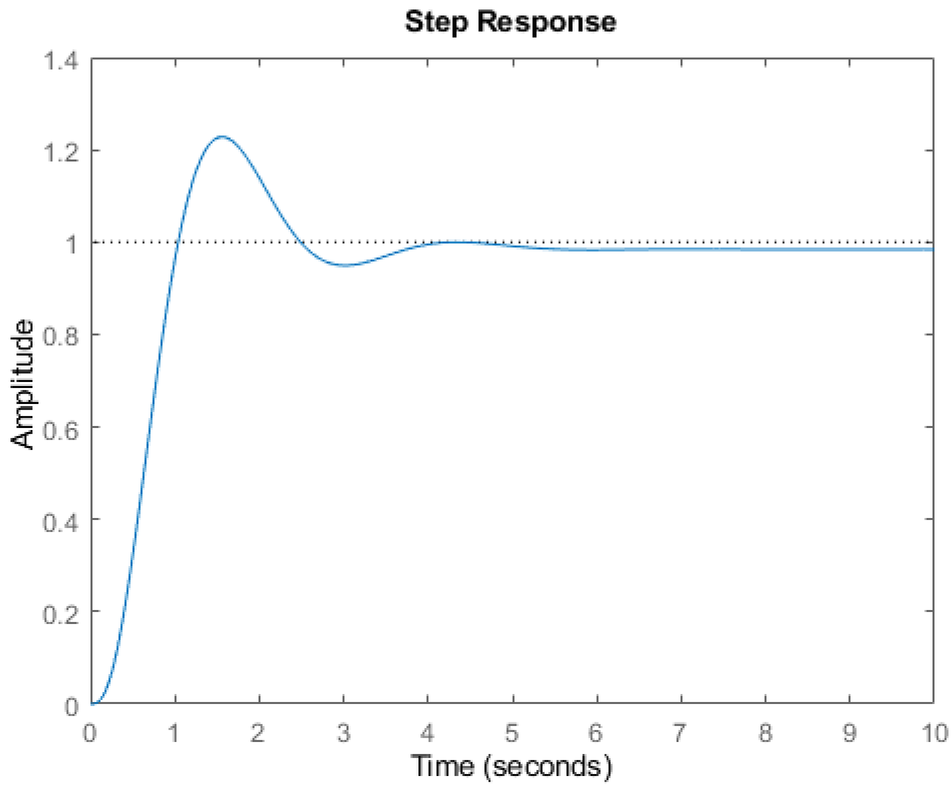

Figure 9 After PI tunning the system

5.3 Fuzzy logic implementation

5.3.1 Fuzzy logic

Instead of the "true or false" logic used in traditional estimates, fuzzy logic is a method of computation that uses a degree of "truth." It allows for more accurate results (1 or 0). Lotfi Zade, a professor at the University of California, Berkeley, is credited with developing the concept of fuzzy logic in the 1960s. Zade elaborated on how a computer could comprehend natural language in his presentation. Just like life and other aspects of the universe, natural language is difficult to describe using absolute numbers such as 0 and 1. The philosophical question of whether everything can be described in two different ways is an intriguing one to ponder. On the other hand, most of the data you want to transfer to a computer is already in a partially processed state and is frequently the result of using a computer.

It helps to see fuzzy logic as a way of thinking about it, except for binary or logical logic. Traditional control methods differ from using a model to designing a controller based on a differential equation and implemented by a model. On the other hand, when it comes to "unclear management," the emphasis is on developing an intuitive understanding of how to properly manage a process and then passing this information directly to a fuzzy controller. For example, if you are on a cruise, you may be instructed to slow down by a human driver. When the vehicle's speed drops below a set limit, it can advise the driver to increase the pressure on the accelerator pedal.

5.3.2 Applications of fuzzy logic

- • The dishwasher employs fuzzy logic to determine the most effective method for cleaning the dishes as well as the amount of energy required to do so, considering factors such as the total number of dishes and the amount of food debris that is present on them
- The voltage on the copier's drum is adjusted by fuzzy logic, which considers various factors, including the density of the image, the temperature, and the humidity.
- Ambiguous logic is utilized in the aerospace industry to control the altitude of satellites and spacecraft in response to external factors
- Fuzzy logic is used in computerized medical diagnoses, which are determined by symptoms and a patient's medical history
- In chemical distillation, fuzzy logic is utilized to control both the pH and temperature of the process
- Natural language processing makes use of ambiguous logic to determine how words and other aspects of language are related to one another in terms of their respective meanings
- The output of environmental control systems such as air conditioners and heaters is contingent on variables such as the current temperature and the temperature at which you want it to be set. It is due to the absence of any clear logic in the system
- Fuzzy logic can be utilized in business rules systems to help make the most optimal decisions possible given the criteria that have already been established.

5.3.3 Fuzzy controller

The fuzzy Controller defines, alters, and uses people's heuristic knowledge regarding system management. The block diagram of the fuzzy Controller is seen in the figure to the right. The picture depicts what seems to be a fuzzily controlled controller. The fuzzy Controller is made up of four primary components. If- Rules are then used to evaluate an expert's explanation of how fuzzy logic may be utilized to improve company operations as a rule foundation, and the results are reported. An expert would suggest the most effective methods to maintain a plant-based on their knowledge and expertise in the field. The input from the Controller may be turned into data that the inference process can utilize using a fuzzification interface. It is referred to as the "defuzzification interface" when translating inference findings into real-world inputs occurs.

5.3.3.1 Applications of fuzzy Controller

- Spacecraft attitude control
- Satellite altitude control
- Intelligent trunk system
- Traffic control
- Decision support system
- Train schedule control Railway and braking system speed
- Quantitative analysis of the model for industrial quality assurance
- Active process monitoring wastewater treatment
- Individual volume assessment
- Improving the efficiency of automatic distribution

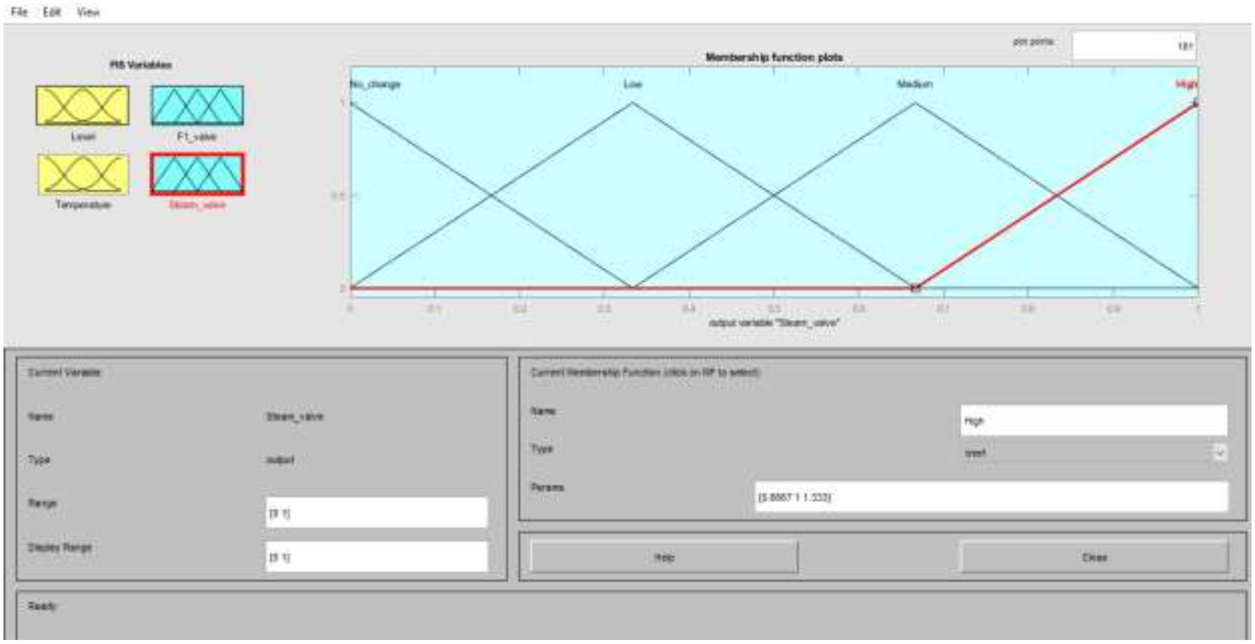

Figure 10 Fuzzy logic main window

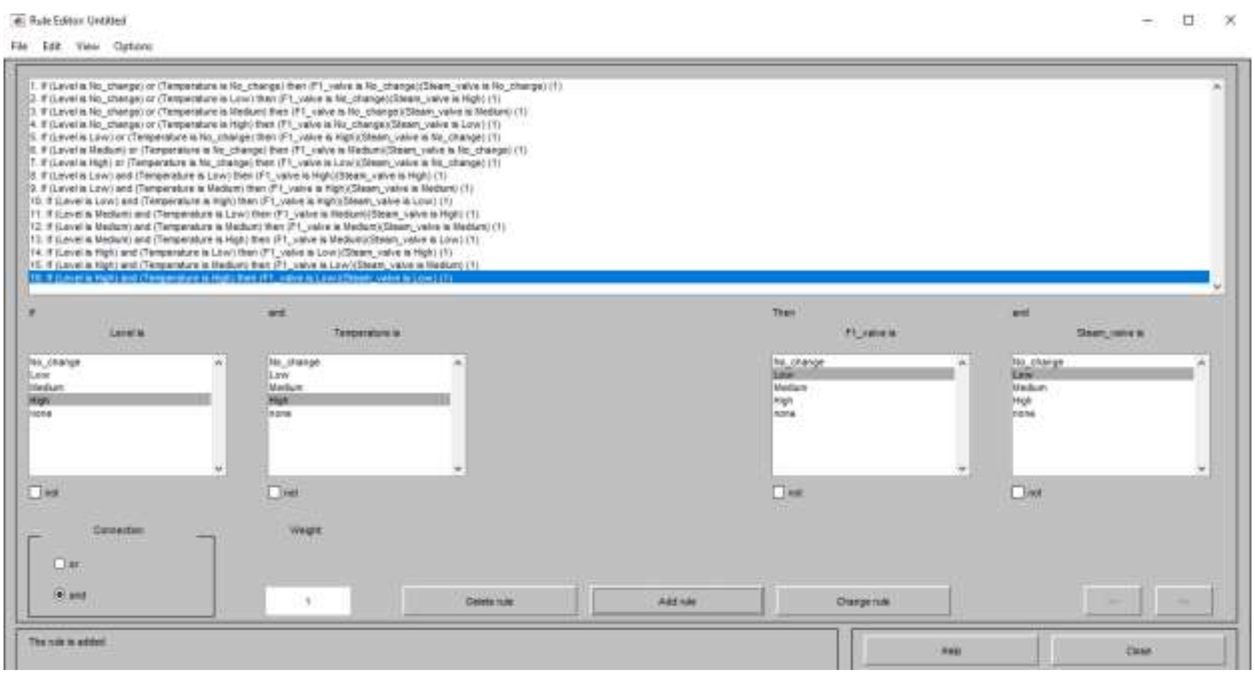

Figure 11 Defining the rules

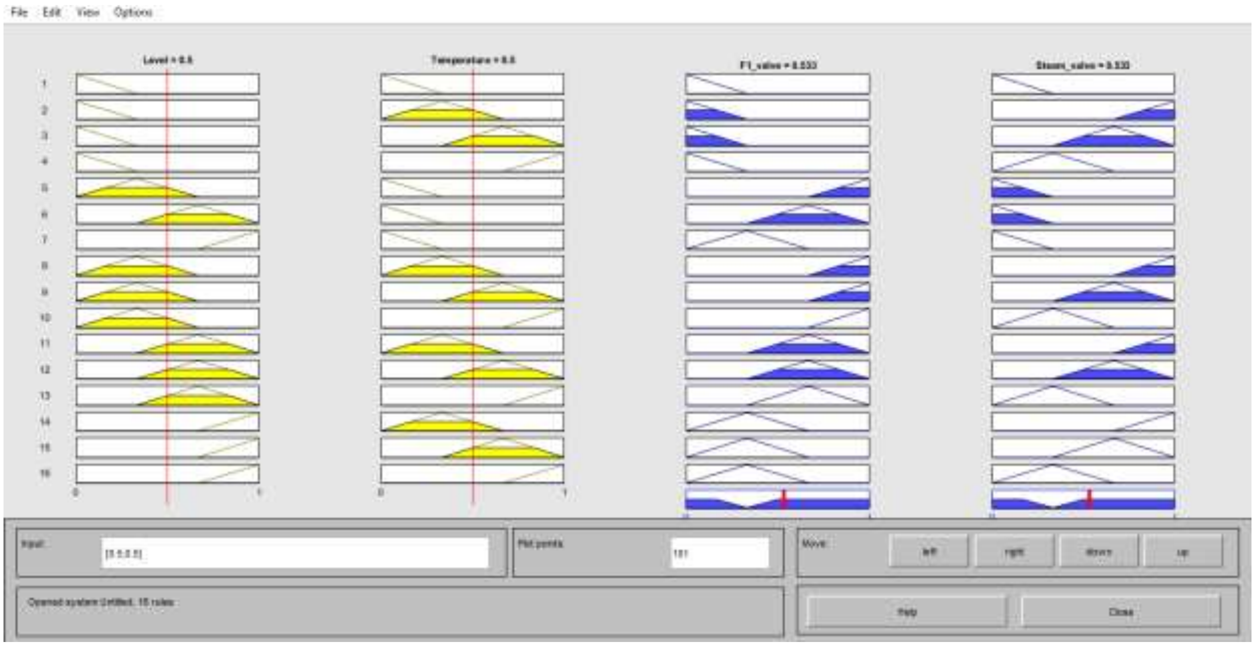

Figure 12 Fuzzy rules output

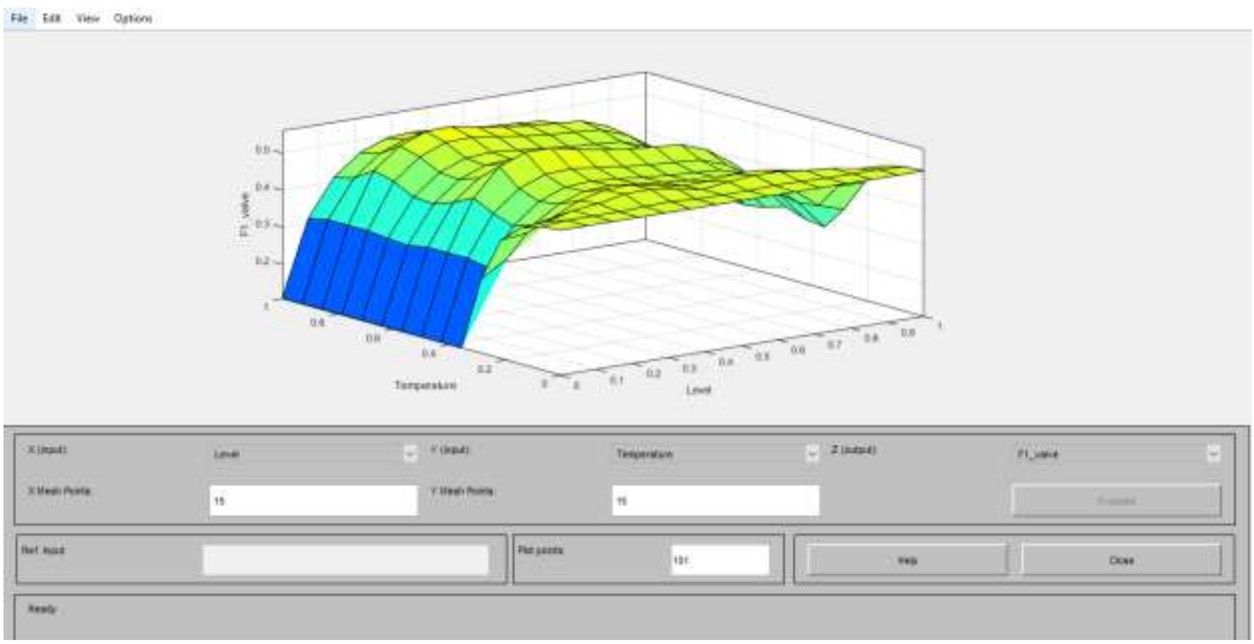

Figure 13 Fuzzy output surface

5.4 Simulink Simulation

5.4.1 Simulink

Simulink is an environment for embedded systems that includes a simulation and block diagram tool. This tool supports the design, simulation, automatic code generation, and continuous testing and verification of system-level designs. Simulink is a modelling and simulation tool for dynamic systems that includes a graphical editor, block libraries that can be customized, and solvers. It is used to create models of these types of systems. It is used to create models of the types of systems. Because of its integration with MATLAB, it is possible to use MATLAB algorithms within your models. In addition, you can export simulation results to MATLAB to perform further analysis on those results.

5.4.2 Tunning through PID in Simulink

The total plant is simulated in the Simulink through the PID tuning. The block diagram and the output results of the plant are given.

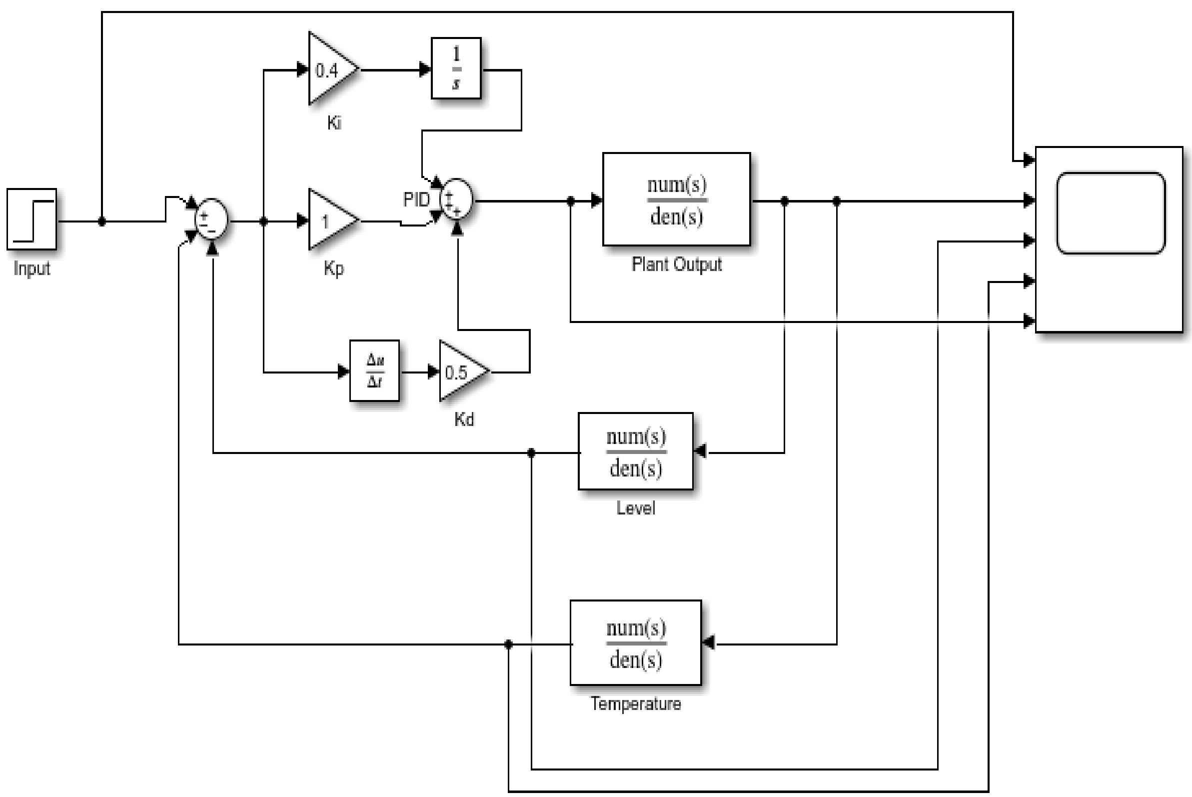

Figure 14 Simulink Model of the plant through PID

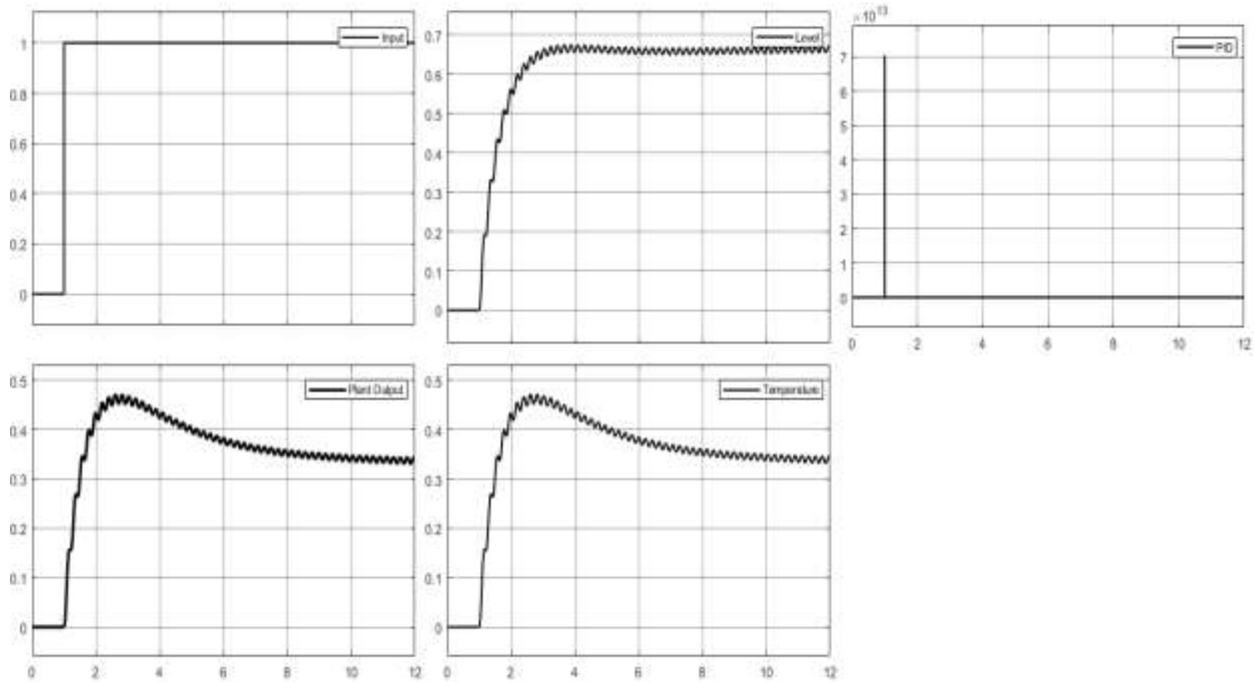

Figure 15 Output tunning of the plant through PID

5.5 Recommendation of PLC

PLCs, which stand for "programmable logic controllers," are pieces of equipment that automate manufacturing plants through the application of ladder logic. I prefer the Simens PLC over the Fatek PLC even though the Fatek PLC is simple to program and use. The Simen PLC may not be as widely used as Fatek controllers, but it is by far the most sophisticated and helpful PLC.

Safety

A person is said to be safe when they are protected from any potential dangers or when they are using an item designed to keep them safe.

6.1 Possible safety

SIFs, which stands for safety instrumented functions, are made up of one or more components intended to carry out a particular safety-related activity if something goes wrong. A switch is a simple safety interlock function, or SIF is responsible for turning off an appliance when its temperature reaches a predetermined threshold. There is a possibility that one of these switches is located on an electric water heater or a clothes dryer. If this switch determines that the temperature is unsafe, it will cut power to the appliance.

In addition, you can use safety instrumented functions, which are also referred to as Instrument Protective Functions, or IPFs for short. You are free to make use of these functions in this scenario.

A Safety Instrumented System (SIS) is a collection of Safety Instrumented Functions (SIFs) designed to make an industrial process that could be hazardous and safe if any potentially dangerous conditions are discovered.

These systems, which are also known as Emergency Shutdown (ESD) and Protective Instrument Systems (PIS), add a "layer" of protection against damage to process equipment, harmful effects on the environment, or human injury in addition to what is typically responsible for by a properly functioning regulatory control system.

An SIS, like other automatic control systems, is composed of the following three components:

- Sensors
- Controller
- Final Control

6.1.1 Sensors

The sensors have detected something in the environment that could be hazardous. So, to make sensors, process switches, and transmitters that are not a part of the regulatory control system can be used.

6.1.2 Controller

The Controller is the one who is responsible for determining whether the process should be terminated at a particular point. A logic solver is a title given to the person in charge of a security information system (SIS). A conventional control system should not be confused with this.

6.1.3 Final Control

If something goes wrong with a procedure, it is the responsibility of the last control element to place the process in a secure state so it can be terminated. In safety instrumented system, specialized on/off valves, sometimes called "chopper" valves or override solenoids, can be used to turn off the standard control valve (SIS).

References

[1].https://en.wikipedia.org/wiki/Feed_forward_(control)#:~:text=A%20feed%20forward%20(sometimes%20written,signal%20from%20an%20external%20operator.

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[3].https://www.west-cs.com/products/c/single-loop-temperature-and-process-controllers/#:~:text=Single%20loop%20controllers%20are%20cost,precise%20control%20for%20demanding%20applications.