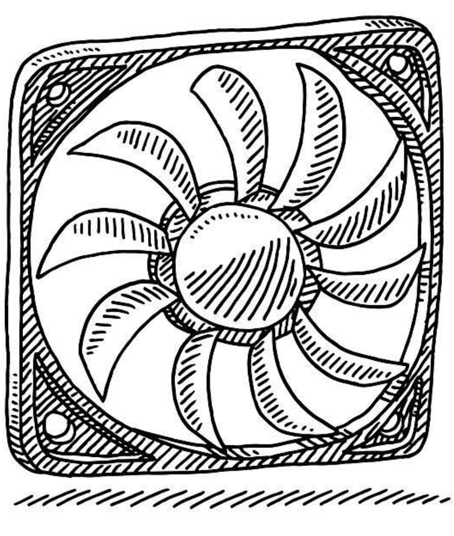
METU

EE407 - Process Control Laboratory

Temperature Control in a Miniaturized Heating Process



Middle East Technical University
Electrical and Electronics Engineering Department

1. Objectives

This experiment aims to explore the functionality of a digital controller in a closed-loop system and control the temperature of a point in the circuit. Working principles of thermistor, fan, and FET will be investigated.

2. Background Information

In this experiment, your task involves designing a controller that maintains a desired temperature for a heating process. The block diagram illustrating the entire system can be found in Figure 1.

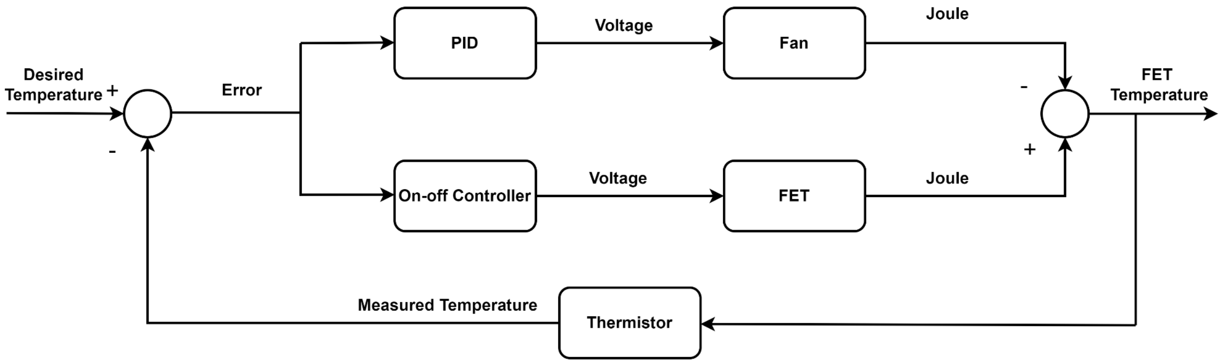


Figure 1. Block Diagram of the system.

Brief descriptions of these elements and their input-output signals are as follows.

FET Transistor:

Power Metal-Oxide-Semiconductor Field-Effect Transistors (Power MOSFETs) are semiconductor devices commonly used for switching and amplifying electronic signals in power applications. The basic operation of a MOSFET involves the application of a voltage at the gate terminal, creating an electric field that controls the flow of charge carriers (electrons or holes) between the source and drain terminals. In this experiment, IRFZ44N, a popular N-channel power MOSFET, serves as the heating element in the system. As its temperature increases, it will generate heat. Although the typical voltage rating for the IRFZ44N is around 55 volts and the maximum continuous drain current (ID) is in the range of 49 amperes, much lower currents and voltages are used in this experiment.

Thermistor:
A Negative Temperature Coefficient (NTC) thermistor is a type of thermistor that exhibits a decrease in electrical resistance with an increase in temperature. This characteristic makes NTC thermistors particularly useful in temperature sensing and control applications. NTC thermistors are often connected in series or parallel with other resistors in a voltage divider circuit in temperature sensing applications. The voltage across the NTC thermistor changes with temperature, and this voltage variation is used to determine the temperature. It acts as a feedback sensor, providing information about the current temperature to the Arduino.

Fan:
In this experiment, the fan serves the purpose of generating airflow around the thermistor to facilitate its cooling. This application serves a dual role: firstly, it induces self-regulation in the heating process, and secondly, it acts as a variable disturbance. In the absence of the fan, heat dissipation to the surroundings is minimal, causing the heating process to exhibit an integrating behavior. To prevent potential damage to the equipment, it becomes necessary to introduce some form of airflow for self-regulation. By adjusting the airflow speed, we can mimic the impact of varying disturbances, thereby allowing us to assess the controller's performance under different disturbance conditions.

Arduino:
The Arduino functions as the controller in the system. It processes the feedback temperature data from the thermistor and executes control logic to maintain the temperature at the desired setpoint. The Arduino code evaluates the feedback temperature and decides whether to increase or decrease the heating element's power. If the temperature is below the desired setpoint, the code may increase the FET MOSFET's gate voltage to raise the temperature. Conversely, if the temperature is above the setpoint, the code might reduce the gate voltage or activate a cooling mechanism. In this project, Arduino Uno will be utilized.

DC Power Supply:
The FET MOSFET, which serves as the heating element in your project, requires a higher voltage to generate heat effectively. To address this, a separate DC power supply is introduced to provide the required voltage to the FET MOSFET. This external power supply can deliver the higher voltage and current needed for the heating process.

Configuration:
In this project, you will construct the circuit diagram as shown in Fig 2. You are going to use a sandstone 33-ohm resistor attached to the source pin. This resistor will be utilized because we need high current flow through the transistor so that the transistor will heat up. In the project, a '5W33RJ' type resistor will be utilized. The Gate pin of the transistor will be connected to the pin 10 of the Arduino Uno. The Drain pin will be connected to the Power Supply. As shown in the circuit schematic, the thermistor will be positioned very closely to the transistor to sense the temperature change in the transistor. The temperature change in the transistor will be transmitted by radiation, convection, and conduction. When the thermistor senses the temperature, it changes its resistance according to the sensed value. Therefore, the

temperature change will result in a voltage change.1k resistor will connect to one side of the thermistor and the other side will be connected to Arduino's 5V pin. The other pin of the 1k resistor will be connected to the 'A0' pin of the Arduino Uno. Arduino will gather the voltage change information from the circuit and convert this information to temperature with a code.

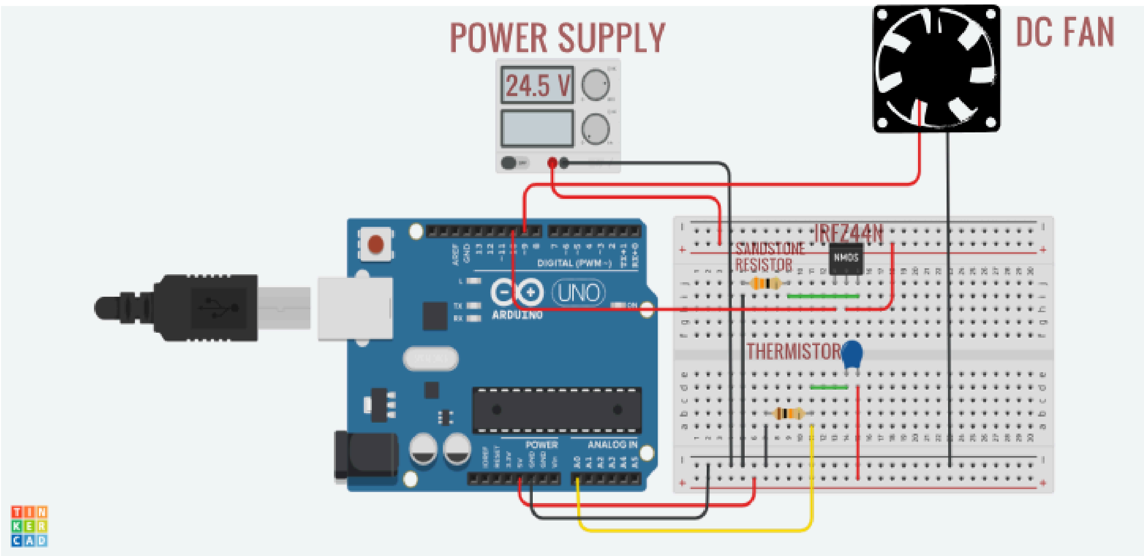


Figure 2. Circuit schematic of the system

3. Assignments

a. Redraw the block diagram of this project. Indicate whether a signal is digital (D) or analog (A).

b. What is our control objective? Explain what each of the following corresponds to in our system: Process Variable, Measurement Sensor, Measured Process Variable (PV), Set Point (SP), Controller Output (CO), Final Control Element (FCE), Manipulated Variable (PV), Disturbances (D).

c. What are the principles of temperature control in electronic circuits, and how do thermistors, FET transistors, and fans contribute to this process?

d. What is the basic principle behind the control algorithm used to adjust the voltages for the transistor and the fan?

e. From the bump test plot given in Fig 3. find the FOPDT model of the plant. (MOSFET heater + Thermistor).

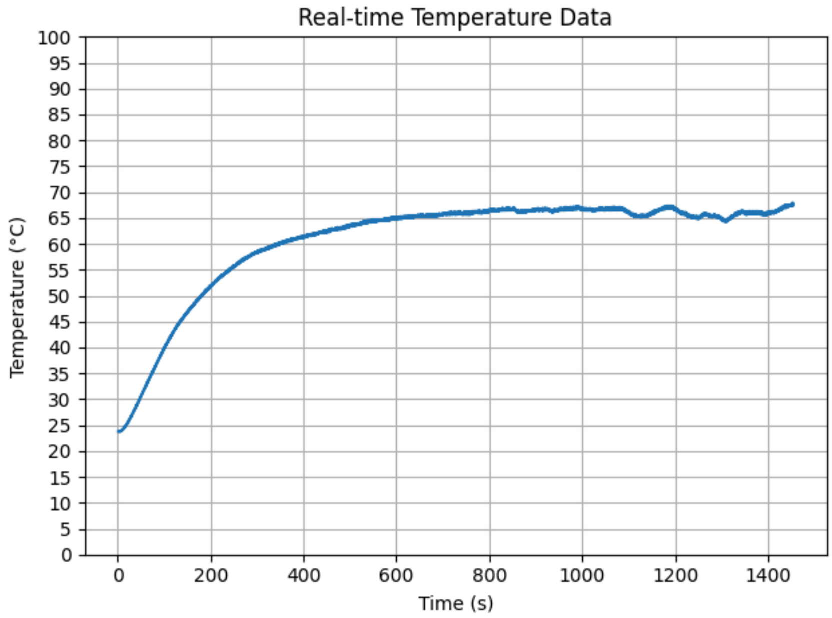


Figure 3. Bump Test result

4. Experimental Procedure

Establish the connections as seen in figure 2.

PART I.

In this part, feedback control is established by only controlling the fan. The MOSFET is just a heating element.

P Only Control

1) From the desktop, find the ee407_project folder.
2) Open the themistor_temp_meas folder.
3) Inside the folder, open the .ino file named themistor_temp_meas.
4) Command out the ON_OFF controller for the mosfet part.
5) Upload it to Arduino.
6) Open the heat_control _interface file from the cmd screen.
7) Proportional control will be tested.Enter the controller parameters you want to test.
8) Firstly, adjust the set point to 50°C. Make sure the MOSFET controller is turned off.
9) Start heating the MOSFET when the MOSFET is at 25°C. Observe the response of the system.
10) Comment on the results.

PI Control

1) Repeat the same procedure 1-6 from the P controller part.
2) In this part, the proportional integral control will be tested.Enter Kc and integral time constant values.
3) Wait for the temperature to drop to 25°C. Adjust the set point to 50°C.

4) Start heating the MOSFET.
5) Observe the response.
6) Comment on the oscillations.
7) Comment on steady-state error.

PID Control

1) Repeat the same procedure 1-6 from the P controller part.
2) In this part, the proportional integral control will be tested. Enter Kc and integral and derivative time constant values.
3) Wait for the temperature to drop to 25°C. Adjust the set point to 50°C.
4) Start heating the MOSFET.
5) Observe the response.
6) Comment on the behavior. Is the speed of the response the same as other control methods? Explain the reason behind your answer.

PART II.

In this part, an on-off control method is used on the MOSFET to control its temperature in addition to PID control of the fan.

PID + On-Off Control

1) Repeat the same procedure 1-3.
2) Remove the comment of the ON-OFF Controller part.
3) Upload it to Arduino.
4) Open the heat_control _interface file from the cmd screen.
5) In this part, the proportional integral control will be tested. Enter Kc and integral and derivative time constant values.
6) Wait for the temperature to drop to 25°C. Adjust the set point to 50°C.
7) Start heating the MOSFET.
8) When the temperature reaches 50°C, adjust the set point to 30°C.
9) Observe the response.
10) Comment on the behavior. Is there any benefit of this approach? Is there any trade off?

<u>Experimental Results</u>

P Controller for the Fan without ON-OFF Controller for Mosfet

In this part of the experiment, a P-only fan controller is implemented without using any controller on the FET. This results in a minor constant offset in the response plot as seen in Fig 4 as. This is an expected result for a response plot with a P-only controller.

The settling time of the response is measured as 170 seconds.
The overshoot percentage is measured as %10.

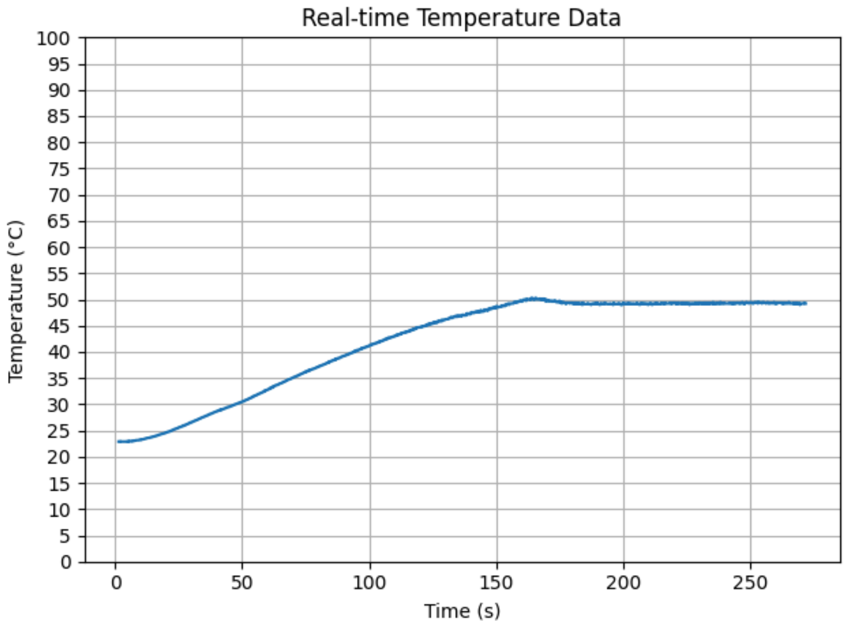


Figure 4. Expected response with only P control

PI Controller for the Fan without ON-OFF Controller for Mosfet

In this part, a PI controller is implemented on the fan without using any controller on the FET again. Normally, observing an offset is not expected since the PI controller eliminates the offset by integrating the error term. Since the requirement of the project is to use a small-sized fan, the performance of the fan is not effective enough to control the temperature of the FET by itself. Therefore, there is a small offset in the response plot.

The settling time of the response is measured as 220 seconds.
The overshoot percentage is measured as %8.

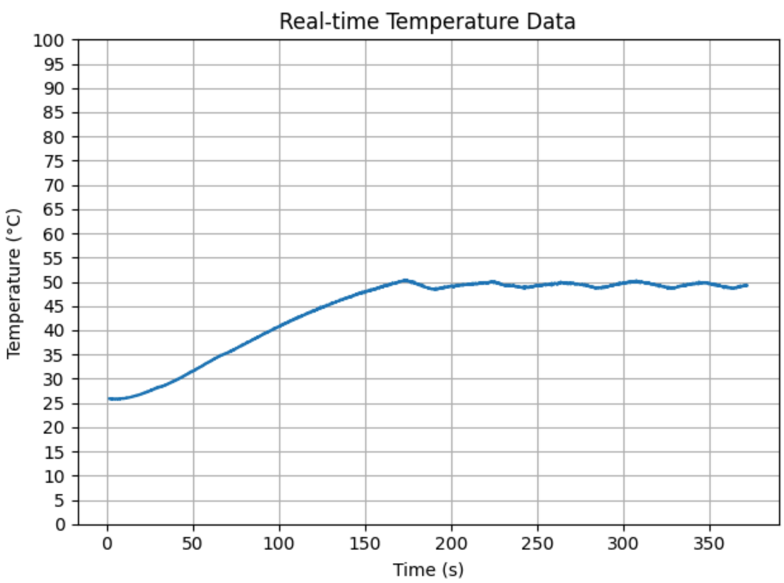


Figure 5. Expected response with PI control

PID Controller for the Fan without ON-OFF Controller for Mosfet

In this part, a PID controller is implemented on the fan without using any controller on the FET again. Normally, the derivative term may potentially speed up the response since it improves the controller's ability to anticipate and counteract changes, potentially leading to shorter settling times. Since the cooling effect of the fan is not utilized from the beginning of the process, the effect of different controllers on the settling time cannot be observed. We have a small improvement for eliminating the oscillations compared to the PI case.

The settling time of the response is measured as 218 seconds.
The overshoot percentage is measured as %8.

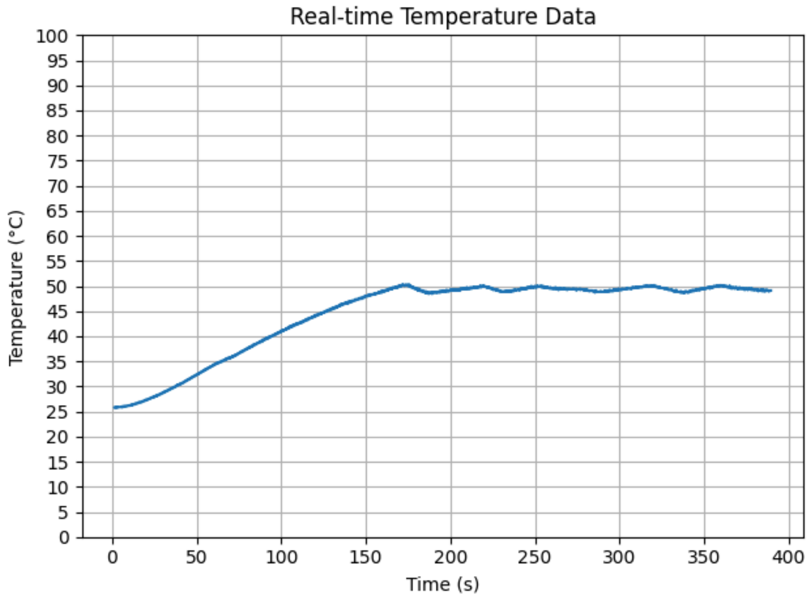


Figure 6. Expected response with PID control

PID Controller for the Fan with ON-OFF Controller for Mosfet

In this part of the experiment, a PID fan controller is implemented alongside an on–off controller for the FET. The On-off controller provides high voltage to the gate of the MOSFET to increase the drain voltage when the measured temperature is lower than the desired temperature. When the temperature exceeds the set point, the gate voltage is lowered so that the drain current becomes zero. Utilizing a controller for FET improves the temperature response of the system compared to only controlling the fan speed.

Since we can control the gate voltage of the mosfet with an on-off controller, we can successfully lower the temperature of the MOSFET to a desired temperature.

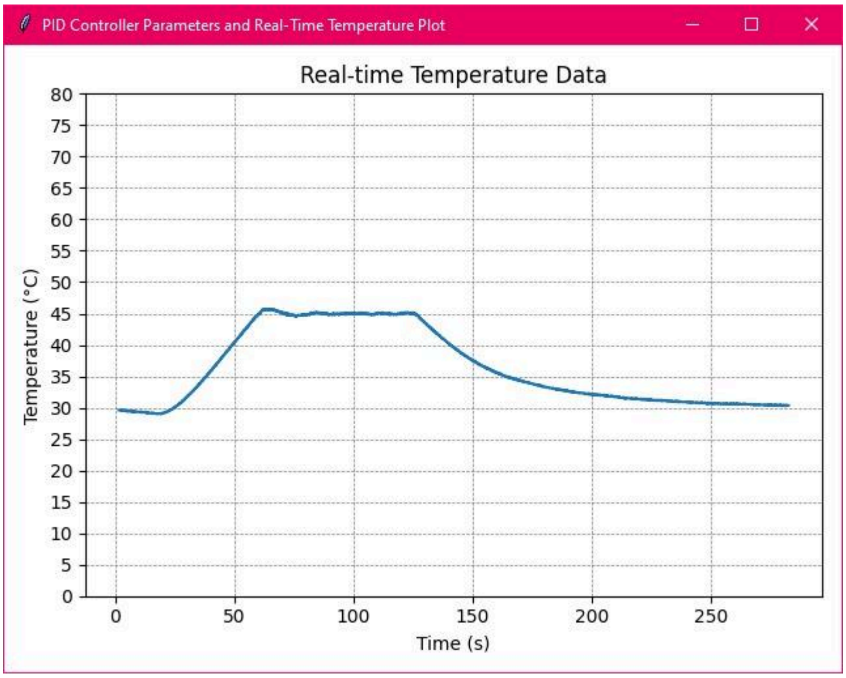


Figure 7. Expected response with PID and ON-OFF control methods

Bump Test Result and IMC Design

As illustrated in Figure 3, a Bump test was conducted on the FET transistor and its results were graphed. By analyzing the behavior of the transistor, we identified the system's characteristics. During this test, it was observed that the current flowing through the transistor was approximately 0.04 A. The initial temperature was recorded at 24.1 °C, which then escalated to 66.8 °C. A gate voltage of 4.45 V was applied. The graphical data enabled us to employ the First Order Plus Dead Time (FOPDT) techniques for system identification. Our mathematical calculations are outlined as follows:

$$Kp = \Delta y/\Delta x \qquad \theta p = t_2 - \tau_p \qquad \tau_p = 3(t_2 - t_1)/2$$

where $y(t_2) = (1 - e)$ and $y(t_1) = (1 - 1/e)$.

Based on these calculations, we derived τ_p =163.5 sec , Kp= 9.6, and for θp=27.5 sec. Consequently, our transfer function is defined as:

$$G_p = (9.6\, e^{-27.5s})/(163.5s + 1)$$

After system identification, we have chosen our desired time constant for moderate performance.

$$\tau_c = max(\tau_p, 8\theta p)\text{=220.}$$

Then we have utilized the IMC Design Table to find the other parameters for our controller and resulted in as below:

$P \rightarrow Kc = 0.1851$

$PI \rightarrow Kc = 0.3154, \tau_I = 163.13\, sec$

$PID \rightarrow Kc = 0.4658, \tau_I = 211.98\, sec, \tau_D = 9.61\, sec$

According to these designed control parameters, we have simulated the controller response using Simulink.

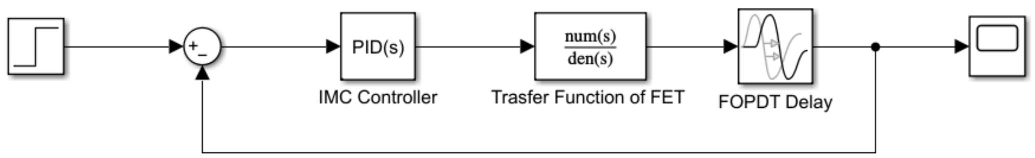


Figure 8. Block Schematic of the IMC Design.

The step responses are shown in Figure 9, 10,11.

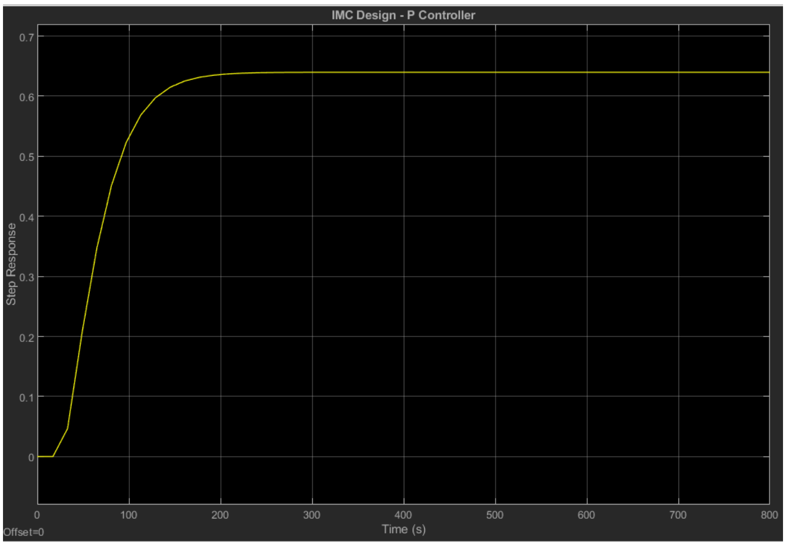


Figure 9. P Controller- IMC Design.

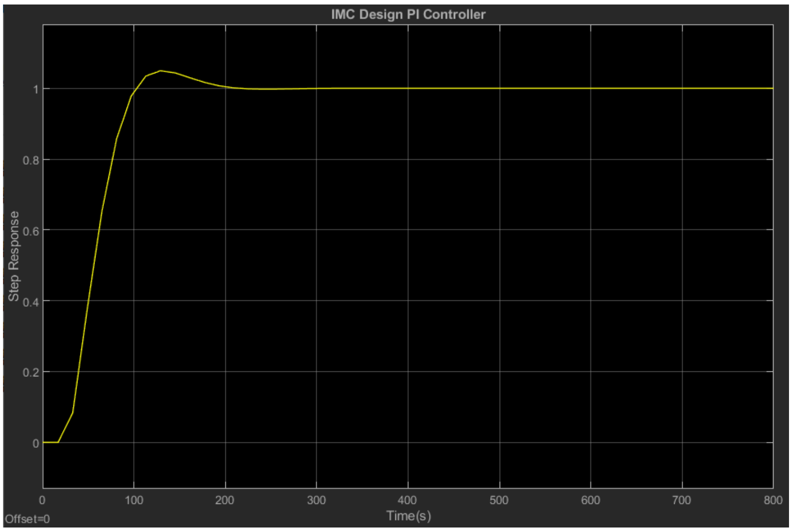


Figure 10. PI Controller- IMC Design.

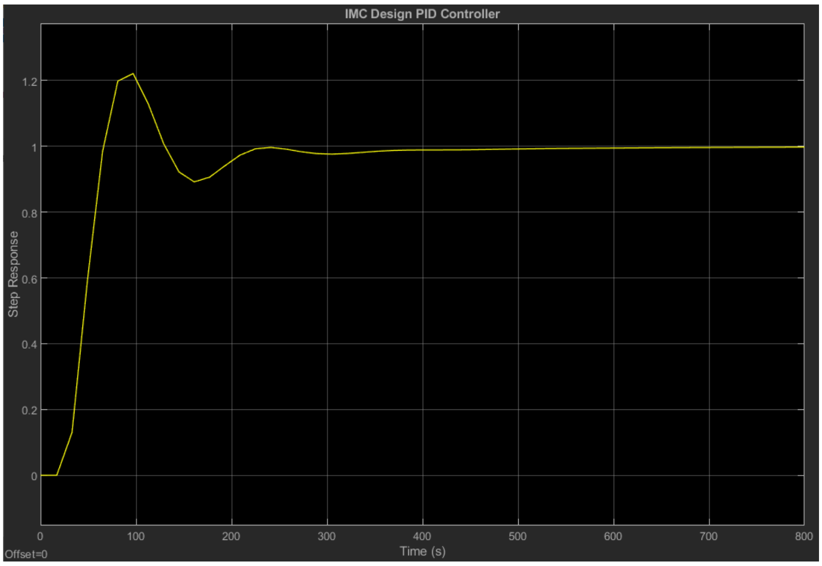


Figure 11. PID Controller- IMC Design.

From these findings, we can deduce that our design parameters are functioning with precision. However, when this controller was implemented in a real-world scenario, the outcomes varied slightly. Primarily, in order to cool the system, it is essential to completely stop the heating process. In contrast, the PID controller merely adjusts the gate voltage of the transistor, rather than reducing it to zero. Despite supplying a minimal gate voltage, the transistor continues to generate heat, which is undesirable. Therefore, we have decided to employ an ON-OFF Controller for this specific task. By doing so, we have attained stability while eliminating any persistent state errors.

Conclusion

In conclusion, this experiment successfully demonstrated the complexities of temperature control in a miniaturized heating process using a digital controller in a closed-loop system. Through the implementation of various control methods, including PID, PI, P, and the strategic addition of an ON-OFF Controller, we gained valuable insights into the system's behavior and response to different control strategies. The experiment highlighted the significant role of components like the FET transistor, thermistor, and fan, and their interaction in achieving precise temperature regulation. The findings from the bump test and IMC Design simulations were instrumental in fine-tuning our approach, leading to an improved understanding of system characteristics and the realization of an effective temperature control mechanism with enhanced stability and accuracy.