2024-06

Design and Development of PID Temperature Controller for Locally Made Electric Injera Baking Mitad

Abebe, Zeleke Amedie

Bahir Dar University

Bahir Dar Institute of Technology (BIT)

School of Postgraduate Study

Faculty of Mechanical and Industrial Engineering

Electromechanical Engineering M.Sc. program

M.Sc. Thesis

Title

Design and Development of PID Temperature Controller for Locally Made Electric Injera Baking Mitad

By

Abebe Zeleke Amedie

June 2024

Bahir Dar

Bahir Dar University

Bahir Dar Institute of Technology (BIT)

School of Research and Postgraduate Study

Faculty of Mechanical and Industrial Engineering

Electro-Mechanical Engineering M.Sc. program

M.Sc. Thesis

Title

Design and Development of PID Temperature Controller for Locally Made Electric Injera Baking Mitad

By

Abebe Zeleke Amedie

Thesis submitted in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Electro-Mechanical Engineering

Principal Advisor, Dr. Tefera Terefe

Faculty of Electrical and Computing Engineering

Adama Science and Technology University (ASTU)

June 2024

Bahir Dar

Declaration

This is to certify that the thesis entitled, **Design and Development of PID Temperature Controller for Locally Made Electric Injera Baking Mitad.**

submitted in partial fulfillment of the requirements for the degree of Master of Science in **Electro-Mechanical Engineering,** under Faculty of Mechanical and Industrial Engineering ,Bahir Dar Institute of Technology , is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during the course of this investigation have been duly acknowledged.

Abebe Zeleke Amedie	______________	**27 -June -2024**
Name of the candidate	signature	Date

Approval of Thesis for Defense

I hereby certify that I have supervised, read, and evaluated this thesis titled "**Design and Development of PID Temperature Controller for Locally Made Electric Injera Baking Mitad**" by **Abebe Zeleke Amedie** prepared under my guidance. I recommend the thesis be submitted for oral defense.

Dr. Tefera Terefe		27-June 2024
Advisor's name	Signature	Date

BAHIR DAR UNIVERSITY

BAHIR DAR INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

Faculty of Mechanical and Industrial Engineering

Approval of thesis for defense result

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis. Name of Student **Abebe Zeleke Amedie** Signature_____ Date Aug. 13. 2024. As members of the board of examiners, we examined this thesis entitled "**Design and Development of PID Temperature Controller for Locally Made Electric Injera Baking Mitad**" by **Abebe Zeleke Amedie**. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Science in "**Electromechanical Engineering**.".

Board of Examiners

Name	Signature	Date
Name of Advisor Dr. Tefera Terefe	Signature	Date Aug .09.2024
Name of External Examiner Dr. Betelay Teka	Signature	Date Aug .11 .2024
Name of Internal Examiner Dr. Addisu Negash	Signature	Date Aug 13, 2024
Name of Chairperson Mr. Birhanu Adisie	Signature	Date 13/08/2024
Name of Chair Holder Mr. Birhanu Adisie	Signature	Date 13/08/2024
Name of Faculty Dean Dr. Bereket Hail	Signature	Date ______

Faculty Stamp

Acknowledgment

First and foremost, I express my gratitude to Immense God for providing me with strength and serenity during the challenging periods of my studies.

I would like to express my deepest gratitude to my thesis advisor, Dr. Tefera Terefe, for his professional guidance, unwavering encouragement, enormous patience, and supportive attitude throughout this thesis. His insightful ideas, comments, and suggestions were helpful. Beyond academic advising, his positive behavior and approach have been tremendous learning experiences to me.

I would like to thank all my parents, especially my brother Eyobe Nigusse and my sister Woyneshet Nigussie. Also, my special thanks to my close friends Grimy Ambisawu, Towderos Degu, Luelseged Belay, and Hana Abebe.

Thanks to the BIT staff and my classmates Mr. Yhenewu Wubie and Mr. Habtiamu, they supported me by providing tools and devices used for experiments work. Also special thanks to W/r Yenewerk Wagay, she provided electric mitad to conduct the experimental test.

I would like to thank, BIT, Faculty of Mechanical and Industrial Engineering Staff.

Abstract

Injera is Ethiopia and Eritrea's most cultural staple food item, made from an Indigenous grain called “teff”. Traditionally 50-60 cm diameter circular pancake is baked on a 20–30 mm thick clay griddle called Mitad. It is the foremost energy-intensive apparatus in Ethiopian households. Mitad needs constant temperature to bake injera in the preferred quality and texture. After it reaches a steady state operating temperature range. However, the existing locally-made electric mitad continuously feeds the power, without controlling the required temperature to bake Injera. However, controlling the constant baking temperature of mitad is challenging due to unpredicted nature of the material to be made and there is no standard material used to make mitad. Over 1.2 million uncontrolled mitad are currently used in Ethiopia.

This study aims to develop an automatic PID feedback temperature controller for locally made electric mitad to regulate overheating and underheating. By detecting the surface temperature of mitad. In contrast, with input power to maintain the desired operating surface temperature. Two major experimental setups are conducted on locally made electrical Mitad. To study the process characteristic of the mitad temperature profile. Since to determine the mathematical model and the transfer function of mitad. A custom temperature data logger is developed and used to collect temperature data. Also, an electric energy logger is used to measure input energy during injera baking.

Based on the experimental data of input and process variables, The PID controller constant parameters were estimated and simulated in MATLAB /SIMULINK and the performance of the controller was determined based on the experimental obtained temperature profiles of Mitad. In this study, the microcontroller is considered as a brain to receive the top surface temperature of Mitad from the sensor and compare it with the set point value. then send a signal to the actuator or solid-state relay (SSR) to take action in the power supply. The controller design, analysis, and modeling investigation were conducted. An energy comparison test has been conducted between controlled and uncontrolled electric mitad. The results show that 16.1% of energy reduction per injera and the average baking time of controlled mitad was reduced by 17.9 % per injera, while it compared with uncontrolled EIBM.

Contents

List of Figures

List of Tables

Acronym

EIBM	Electrical injera baking machine
PID	proportional integrative derivative
PI	proportional integrative
SSR	Solid State Relay
FOPTD	First order plus time delay transfer function
PPADV-SSR	proportional phase angle digital voltage solid state-relay
EMIM	Electromagnetic Induction Injera Machine
MC	Microcontroller
IDE	Integrated development environment
I/O	Input Output
PV	process variable
CV	Control variable
K_p	The steady state gain.
τ_p	Time constant,
θ_p	Dead time
s	Laplace transform variable

CHAPTER 1

Introduction

1.1.Background

Injera is the most cultural staple food in Ethiopia which is produced from the commonly used crop called Teff (Eragrostis Teff) and also other crops are mixed with teff such as millet, sorghum, maize, wheat, etc. Yeast reached flatbread having soft and sponge texture with craters in the front face small holes. The baking process of injera uses a traditional circular plate made from clay with a diameter of 50- 60 cm called Mitad. The most common type of energy sources, used for heating mitad are biomass biogas and electrical energy [1]. Solar energy which is under study and trying to be implemented [2]. In Ethiopia, cooking and injera baking consume 90% of household energy out of this 50-75% of energy is consumed by the injera baking process. The traditional biomass injera stoves are inefficient in terms of energy use [3]. The sources of energy are difficult to control and to achieve the ultimate desired efficiency [4].

The efficiency of mitad varies due to the sources of energy used and also methods of applying energy sources. Traditional clay mitad that uses biomass energy has 5–15% efficiency and modernized biomass burners have 25-35% efficiency [5]. The rating power of the current electric mitad is estimated at 3-4 Kw, with 45-52 % efficiency, the remaining 55-48% energy is lost.

(a) (b), (c) (d)

Figure 1.1. The sources of energy used for injera baking mitad

The primary factors influencing the energy consumption of Mitad is its thermal diffusivity, heat capacity, and thermal conductivity. The time it takes for mitad to heat up is influenced by its thermal diffusivity and conductivity. Through field testing, the baking temperature and injera heating time on local mitad are determined [6]. The majority of Ethiopia's household electric energy is consumed by electric injera mitad, which is the most widely used energy-intensive appliance in the household. Electric injera baking mitad technology started in 1960 [7]. To use electric energy sources for baking injera, now it is widely manufactured using simple hand tools and equipment. It is produced by micro and small firms and used in urban Ethiopian cities.

Depending on the layer of clay, Recently, three different forms of electrical mitad have been utilized: single clay, double clay, and rotating type of mitad. The average power consumption of existing mitad is in the range of 3.5- 4 KW, however, it loses 50-60% of the input energy[1,8]. The baking time of injera varies in the process of baking mostly it takes 2- 4 minutes to bake one injera. The existing locally made mitad takes a long time to start baking until the clay or griddle heats initially[9]. So, keeping the minimum temperature of mitad is important, if it drops below the minimum required, it takes a long time to heat up again and consume more energy.

Large heat losses exists, during the process of baking, when using an electric mitad, which results in extra electricity costs for the consumer. The reason is inefficient electric mitad and there is no power and temperature regulator used for locally made mitad. The practice of uncontrolled electric mitad linked to energy waste and inefficient household appliances in urban Ethiopia[9,10]. The government and other institutions have pushed for the implementation of efficient new technologies, with limited success. The heavy dependence of national grid electric energy for many applications from households up to the industrial level, and using inefficient nonstandard devices are the causes of energy loss as a result of a high amount of electric energy loss at the national level.

The required surface temperature of locally made electric mitad for injera baking is not estimated exactly. Due to the manufacturing processes of mitad not being standardized yet the thickness of clay and the size of mitad vary. So, the variation of parameters in each locally made mitad results in power rating variation. But one process makes them common most of them do not have a controller to regulate the process of baking. Once it starts operation until the end of the baking process the power is supplied. As a result, extra energy applies to mitad, even if the required or desired surface temperature reaches beyond the maximum. It increases the demand for electric energy and exposes it to wastage.

Study shows that the deployment rate of electric Injera baking mitad is rising, due to urbanization, and relating to the following factors, the energy price is low, suitable to use easily in the house, and free from indoor pollution. In addition to this, the efficiency of electric mitad is relatively higher than the other energy sources used. In terms of safety, it is also good [6].

Recently different research studies have attempted to enhance the efficiency of EIBM, and show significant results and implemented in the injera baking process that enhances efficiency. In the meantime most research studies were focused on enhancing the thermal conductivity of the material to be made and the physical size of the thickness and diameters of mitad, and thermal insulation, due to material change there is a significant improvement in power, time, and economic saving. Also, the research study focuses on the resister heating element, its quality length, and diameter of wire, and heat distribution. Automated electric Injera baking stoves were introduced to increase the efficiency and production rate of Injera baking. Incorporating thermostats to reduce energy loss due to overheating. As a result 30% efficiency increase [11]. Electromagnetic induction mitad was developed with a microcontroller to improve power consumption, as a result, consumption was reduced by 50% and efficiency increased by around 30% when compared with the resister type of electric injera mitad [12].

However, there is a means of controlling the options of the cooking device process variables. The most significant variable to be controlled is the temperature of mitad in the baking process. Operating at the optimal desired temperature range can reduce the power supply and baking time. So that from the existing mitad can reduce energy consumption at the national level. The traditional power on and off switch, which integrates or connects to the electric mitad, should be changed by the proposed microcontroller base, electrical switch assisted by a power electronics device, and appropriate circuit design for mitad to control, the desired minimum and maximum injera baking temperature. To regulate the steady state operation conditions and process disturbances. This will make the process more efficient and power saving, also impact the national level and encourage to use the energy saving devices.

Figure 1. 2. Power supply system of locally made electric mitad

Microcontroller and power electronics circuits are used to drive and control the supply power of the proposed plant (or EIBM) proportional to the output temperature. As a means of regulating overheating and under heating. While it saves energy and time without compromising, the quality of injera. Through process control. It has an advantage for individual households and the national power supply sector to reduce the energy consumption of electric mitad. Over 1.2 million non-standard and uncontrolled electric mitad are used in Ethiopia. In urban households, 60-70% of electric energy is consumed by electric mitad [12]. Only a few studies have been done on the process controller of electric mitad. It requires a process controlling mechanism for the existing electric mitad, while to make efficient and save energy, without changing the material which is made from.

The rating power of the current electric mitad is estimated at 3-4 Kw average power use, with 45-52% efficiency, the remaining 55-48 % of energy is lost. In Ethiopia, more than 1.2 million, locally made electric mitad are used. Considering the minimum household weekly baking twice for 2 hours[12]. By taking the minimum rated power of mitad, the annual minimum energy consumption of electric mitad throughout the country is estimated to reach about 691.2 GWh. So, from the estimated amount of energy considering the maximum specified efficiency, a minimum of 331.8 GWh, energy will be lost. As a result of inefficient electric mitad. This indicates the need for process baking improvement and an automated controller for locally made electric mitad to mitigate the energy losses.

1.2.Statement of problem

Over 1.2 million, non-standard and uncontrolled electric mitad are used in Ethiopia. In the urban household, 60-70% of electric energy is consumed by electric mitad. The rating power of the current electric mitad is estimated at 3-4 Kw, with 45-52 % efficiency. The power supply system of the existing, locally made electric injera baking mitad is continuous from the initial to the end of the baking process. After initial startup heating time, mitad needs constant temperature to bake injera in the preferred quality and texture. However, the existing locally made electric mitad is a continuous power supply system, without referring to and controlling, the output required temperature to bake Injera. As a result, it causes overheating and sticking of injera on the top surface of the mitad. Women take action by spraying water on the top surface to reduce the surface temperature of mitad. This practice leads to energy waste and some of them switch off the power manually. The decision is performed by the person, meanwhile at the dynamic injera baking process. This uncontrolled energy supply system leads to electric energy waste at the national level and brings high energy costs to the individual household.

An electromagnetic induction coil heater type Injera mitad prototype is developed and works under low Injera baking temperature and the energy consumption is reduced by 50% reported, using a temperature controller. However, this type of heat generation is good it is commercially not widely deployed like the electric resister heater type injera baking Mitad. However, there is no process controller used on the existing resister heater electrical mitad, which is practical to regulate the power supply. Few research studies have modeled through different controller algorithms, and the heat generation process also varies.

1.3. Objective

1.3.1. General Objective

Design and development of PID temperature controller for locally made electric injera baking Mitad.

1.3.2. Specific objective

1. To develop a temperature data logger to measure actual plants experimentally and to obtain a Mathematica model for locally made EIBM.
2. To determine the model parameters from experimental data
3. Design proportional and integral PID controller
4. Develop programming code to integrate the microcontroller with the controller circuit to control the desired temperature of Mitad
5. Develop the control circuit, test and implement it in the actual plant
6. To study energy saving options of controlled and uncontrolled electric mitad

1.3.2. Scope of the Research

This research is intended to design an automatic PID temperature controller for locally made electric mitad through experimental tests. Using software and hardware integration on the plant to regulate the system input and output. Microcontrollers are used as central processing units to process control, data measuring, and storing and also process control. To design and simulate PID controller and estimation of parameters based on temperature profile experimental data and energy consumption of the plant. The primary experimental data of mitad is used to design the controller. Test the controller and evaluate energy-saving, options with uncontrolled plant energy consumption.

1.3.3. Limitation of the study

In this study only one locally made electric injera baking mitad test as a plant model, which made from a resister type electrical heating coiled. Having a diameter of 57 cm, used for system modeling. Also, the heat capacity of mitad is not studied experimentally based on a material science point of view. While considering the baking time of mitad after the electric power is switched off, is used explore for energy storage capacity of clay of time in this study.

1.3.4. Significant of the study

- The study significantly reduces the energy loss of EIBM, regulates the input power supply, and alleviates manual cooling of overheating mitad.
- Protect overheating and undereating of EIBM by sensing the desired temperature,
- Continuous monitoring of process variables (or temperature) to keep the quality and texture of baked injera, based on characteristics of existing Mitad.
- It promotes to use of efficient process controllers for EIBM while to save power, time, and electric energy bills.
- While it is remarkable to support the standardization of EIBM
- Nationally it reduces the energy demand of the household

1.3.5. Research Motivation

The most frequently used household high energy intensive device, in Ethiopian kitchens is electric Mitad. Recently in Ethiopia, more than 1.2 million locally made electric mitad are using. The efficient range of 45-52 % indicates a high amount of energy loss, the loss is mainly in the form of heat energy. Since the energy supply and process output are not ben controlled properly. It can be reduced by applying a process controller, to reduce energy being wasted. Considering the existing technical problems of EIBM, this is the motivation for this study. So, by referring required (set) minimum and maximum surface temperature of mitad. Can reduce the energy loss of electric injera mitad. If the surface temperature of the injera baking mitad reaches the required range, it needs a process controller to keep steady-state effective baking.

This can be achieved by applying a controller for existing electric mitad to reduce energy losses. The controller operates based on a feedback temperature sensor to balance the input power and output temperature[13]. In this research PID feedback controller is proposed to develop a controller. Using microcontroller and solid-state relay used to control the process. The possible proposed controller circuit diagram is shown in the figure below.

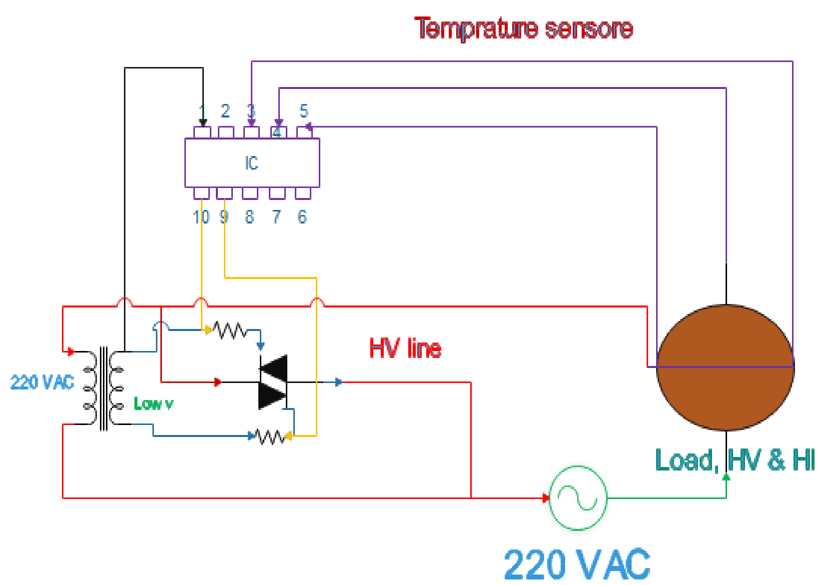


Figure 1.3. Schematic block diagram of the plant and control system model

Chapter 2

Literature review

In this section review of recent research works about the injera baking Machine, the process of cooking, working principles, and major energy and efficiency improvement methods are explored from previous works, and heat loss and research efforts are discussed. Control strategies are used to regulate optimal cooking temperature. Challenges of injera baking process and its temperature controlling strategies being assessed. Then survey on the type of controller used for temperature controlling strategy including PID controllers and related works was discussed.

2.1. Overview of injera baking

Injera is baking using a traditional circular plate made from clay with a diameter of 50- 60 cm called Mitad. The most common type of energy sources, used for heating mitad are biomass biogas and electrical energy [1]. In Ethiopia, cooking and injera baking consume over 90% of household energy, and 50–75% of energy is consumed through injera baking process [14][9]. Traditional and more recent biomass injera stoves are inefficient in terms of energy use[4,15]. Baking injera using, three stone stoves firewood injera baking process has an efficiency of 5–15%. Which indicated that the process needs high energy. This leads to issues like deforestation, global warming, and indoor air pollution [5].

Research confirmed that rural households in Ethiopia used an estimated amount of 50 million m^3 of wood per year for cooking and lighting. This has contributed to the rapid loss of tree resources [6]. Electrical injera mitad is the best possible alternative for urban Ethiopia, which can access the national grid [8]. It overcame all the problems listed above. On the other hand, electric injera baking mitad is net zero emission, and also does not bring any health relate problems. The first electric injera baking mitad was created by the Ethiopian electric power authorities. The efficiency is around 45% - 55%, which is greater by 8-3 times of the traditional one [16]. The electromagnetic injera mitad (EMIM), the prototype was created to address the limitations, shown in the existing, Nichrome resistive heater electric mitad. From this investigation, the power usage was cut in half, the initial heating time was slashed to 48%, and the efficiency was raised by about 34%. However, the improved type of mitad has good efficiency, interims of energy use, biomass burning methods, the material of mitad to make from, and physical sizes are the main factors that take researcher's attention. In Ethiopia it is expected to implement an energy efficiency standard and labeling program that will result in significant energy savings and lowering GHG emissions. That relates to the source of energy and the way to apply it. Renewable energy sources are proposed to bake injera using a solar thermal energy source, using storage and phase change material to bake injera at 180-220 ^{o} c [2,7]. The development of electric injera baking mitad technology started in 1960 [7]. To use electric energy sources for baking injera. In urban Ethiopia households, electrical energy consumption is accounted for by electric injera mitad. Which is the most widely used energy-intensive appliance in Ethiopian kitchens [17]**.** It is widely manufactured using simple hand tools and equipment. Produced by micro and small firms and used in urban Ethiopian cities. To disseminate and adopt electric mitad, various government and private organizations produced and sold[18]. Since the electric injera baking stove is not standardized, the performance of the device is not predicated but it depends on the experiences of the company and the quality of the workmanship.

The absence of standardization of electric mitad, its size, quality of resistors heater used, types of clay used, and improper installation are the main reasons for the inefficiency of electric mitad[1]. Which have been investigated and foreseen. However, it does not have a similar power rating, even if when it is produced by the same manufacturer[3,9]. Typically resistor type of heater used for mitad has resistance values of 22.9, 23.1, 26, 28, and 30 ohms[9]. Nickle chrome or Nichrome resistive heater used for locally made Electric Mitad, Nichrome is a silvery grey color, has good resistant to corrosion, its melting point of 1,400°C and has a resistivity of around 112 ohms, this value is higher than other materials listed above. Since 2007, there have been an estimated 1.2 million locally made electric injera mitad in use recently. The demand rate increased by double till 2018 reported [16]. An excellent substitute that is gaining popularity, particularly in cities [9]. The study was conducted in Weliso, Town to identify the determinant factors for the adoption rate of electrical mitad in the residential house. Non-adaption of electric mitad is affected by many reasons among which the dominant factor is the price of electricity, being expensiveness[19].

In Ethiopia, electric injera mitad consumes around 60% -70% of the total household electric energy. Efficiency improvement is significant to increase the adaption rate rapidly. Because improving process baking can reduce, the power demand and reduce heat loss.

The table below shows that, when WassGrill is compared to other listed EIBMs, efficient based on its construction, low power rating, and use of adjustments temperature controller. Also, few studies try to apply controllers, and different controlling strategies, such as Electromagnetic Induction Injera Mitad developed by Feleke Fanta the baking process controlled using a microcontroller. Also, the automated electric injera baking Stove investigated by S. M. Negash regulates overheating temperature using a thermostat controller.

Table 1. Review efficiency improvement strategies of electrical mitad.

Author	Title	Energy saving method (option)	Baking temperature in ^{o}C	Rated power in kw	Starting time in Minutes
Fetene & Kishor 2021 [9]	Design and analytical study for influence of thermal insulation on Ethiopian electric injera baking pan (mitad)	Study on insulation and resistive element	200 ^{o}C - 250 ^{o}C	3.75 - 4.0	
Feleke Fanta1, Dr. Vinyl Ho, 2019	Improving Performance of Electromagnetic Induction Injera Mitad Feleke	By Changing the heating generation system, an Electromagnetic way	150 ^{o}C - 180 ^{o}C	3 – 3.5	5-8
Robin Jones, Jan Carel Diehl, 2017 [20]	Improvement of Existing Electric Mitad by Mechanical Thermal Design Alteration for Heat Loss Reduction	By changing the resistor heating element and its pattern and material test on magic mitad (MM) semi-controlled	---	2	17
Feleke Fanta M 2020	Improving Performance of Electromagnetic Induction Injera Mitad	Temperature regulating using microcontroller	150 ^{o}C-180 ^{o}C	1.7	5-8
S. M. Negash1, Omiogbemi 2021[11]	Development of a Partially Automated Electric Injera Baking Stove with Improved Efficiency and Production Rate	Appling thermostat controller to regulate overheating	160 – 200 ^{o}C		13 to 15 minutes
Mesele Hayelom Hailu [8]	Energy Consumption Performance Analysis of Electrical Mitad at Mekelle City	Using rotating type mitad to use both the surface of mitad	Baking 130 ^{o}C	3.5 - 3.9	20 for single clay 24 for double clay
	WassGrill cooking Machine	Control Knop semi on and off temperature-controlled system	121 ^{o}C -232 ^{o}C	1.2	2-3

The above review shows that most of the research works are focused on efficiency improvement, based on thermal insulation and material improvement to increase the thermal conductivity of mitad a few studies have been conducted on the controller such as developing Electromagnetic Induction Heating type with temperature controller using microcontroller. However, such research does not exactly solve the existing problem of resistive electric heater type. The review indicates, there is a research gap in existing electrical mitad injera baking process controllers.

2.2. Controller

The practice of adjusting one or more parameters or variables to keep, within a predetermined range is called a control system. The closed-loop control system is one of the control system models, where the desired value effect is set by the amount of output. The difference between the controlled variable value and the desired value is then feedback to the controller [21]. The most widely used control is a PID control of a single closed-loop [22]. The best PID regulator has no operating amplifiers, capacitance, resistance, or other analog electronic components. Instead, it uses mathematics to directly operate on the set value and feedback value, obtaining difference errors to modify[23]. Close loop control using a PID controller is influenced by three parameters substantial contributions of proportion, integral, and derivative. The three constants can be adjusted, so that one or two stand out more than the others.

Feedback loops are commonly employed by PID controllers in industrial and control systems settings. The difference between the desired set point and a measured process variable is the error value. While making an effort to reduce the value, the process inputs should be controlled based on the output's response to bring the process variable closer to the set point [24]. When a mathematical model of the process or control is too intricate or unknown for the system, this approach is most helpful. PID settings must be changed based on the particular application in order to improve performance, to make the system more responsive.

The total system response is influenced by a noticeable constant [25,26]. The microcontroller-based temperature control is used to control process baking of EIBM by sensing the surface temperature of mitad at two points at the center and edge. While using a thermocouple and Maxx 6675 module to convert the analog to digital read. This research work aims to control the process of baking surface temperature of locally made mitad. Which has rated power consumption l measured Values of 3.5- 3.7 kW. Register type electric heater used, has a diameter of 57 cm made from clay Process which is being heated up to a set temperature from 180-219 ^{o} C range after dilution of mitad[9].

The heat is generated by the heating coil when the current passes through a heating element. The thermal energy heater produces is directly proportional to the square of current passing through the coil [27,28]. Local-made electric mitad does not have temperature control devices, to make the power supply proportionality for the required baking temperature. such as a thermostat, and thermocouples, used to reduce heat loss by closing and opening the energy sources referring to the set point only [5]. Which requires sending feedback to the controller and balancing the power supply for the system. The average power consumption of locally made mitad is estimated at 3.22 Kw with an efficiency of around 45%, the initial starting time takes 18 minutes to be ready for baking injera, which is a high starting period [16].

2.3. Temperature Regulation Methods in Electric Injera Baking Mitad

Problems relating to Mitad overheating and underheating are the main issues in the existing Injera Cooking plates. This is due to a lack of temperature controllers, standardized plates, and construction efficiency. This review focuses on the temperature controller mechanisms of cooking stoves. There are research gaps in temperature regulator application to overcome overheating and underheating in electric IBM. Only a few researchers have conducted on and off-controllers to set point temperature [29].

The first recent study focuses on Electromagnetic Induction Injera Machine (EMIM) applying on-off controlling mechanisms to maintain optimum temperature using a microcontroller [16]. Research focuses on induction cooking applications studied and tested efficiency, safety, and energy consumption are good compared with commercially[30]. The main components of EMIM are a resonant inverter to generate high; frequency current coil and cast-iron work peace. The electrical supply voltage is 220V at 50Hz frequency and a 24V DC power supply to the electromagnetic relay fan[12]. The 5V DC supply powers the microcontroller. The fan protects the electronic components from high heat damage as a result of the baking process. During start-up, the selector switch controls the power flow to the coil.

2.4. Type of controller model

A controller is a device that keeps and modifies the operating conditions of a certain dynamical system, according to control theory. Adjusting some input variables can have an impact on the system output variables or the process variables. The controller is used to change the properties output variable of the system [31]. such that, over time, it acts in a particular, desired manner on-and-off control is a simple control system in which the control output is either full or there is a deviation from a set point[32]. Secondly, PID control is a control method in which the value of the control output is a linear combination of the error signal integral, and its derivative [27]. Provides precise control and is used for systems that have frequent disturbances. The review shows that PID control is widely used in different applications because it is simple to implement[23,30]. PID algorithm has good control performance and higher accuracy [23,33,34]. The PID intelligent temperature controller has no resistance, capacitance, operational amplifier, or analog electronic components circuit, it directly uses arithmetic operation using software for set value and the feedback value, and gets difference error to adjust the PID regulator or output [23,35].

PID intelligent temperature controller uses a single close loop control mode. The structure includes a single microcontroller, heating element, and sensor[36]. For the development of a control algorithm, the complete algorithm must meet the required set point. The algorithm has been developed on a powerful workstation supplemented by accurate sensors and actuators. Measured analog variable temperature converted to voltage using an analog-to-digital converter [37]. The microcontroller, as a control unit digital technique is used for the temperature control [38,39]. A fuzzy Logic Controller (FLC) is one of the most powerful controllers, which can control non-linear and it is one of the intelligent control systems that are a successful solution to many control problems [40,41].

Modeling and simulation studies are successfully carried out using Matlab/Simulink software. MATLAB-based simulation techniques are easier and quicker for simulation using a transfer function model. Implementation of the modern PID controller such as fuzzy and integrated fuzzy will lead to better performance of the system [41,42]. The fuzzy logic controller is fast in response to settings and more stable against external disturbance compared to PID [43,44]. Intelligent controllers have risen as an alternative to conventional control methods. To substitute human mind abilities in decision making and learning new functions are imitated [45,46]. One of the most popular intelligent control methods is Fuzzy Logic Control, which utilizes fuzzy logic to convert the linguistic control strategy based on expert knowledge into an automatic control strategy however the cost is high and used for complex systems [43,47].

2.5. Microcontroller-based Temperature Controller

The microcontroller-based temperature controller is used to control the overheating temperature of locally made mitad temperature[48]. It operates at the temperature range of 180-215 ^{o}c, diluted mitad. To control the temperature of the heating coil the current through the heating element should be controlled [49]. The thermal energy produced by the heater is directly proportional to the square of the current passing through the heater coil [28]. Local electric mitad have no temperature control device and Control system. A control system is a set of devices that manage, command, direct, or regulate the behavior of an electric mitad, to control the minimum and maximum surface temperature of the Mitad using, a thermocouple to reduce waste energy [5]. The circuit presents the design, construction, development, and control of an automatic switching electric heater. The idea is based on the problem that occurs in electric mitad overheating at the time of baking injera to improve the existing technology[50]. The Peripheral Interface Controller (PIC) based automatic temperature control system was applied [22,27,42]. The baking process can be automatic using the embedded feature [28,46]. The electric heater will automatically switch on according to the temperature that falls below the specified limit. The system monitors the temperature from the thermocouple sensor, where it will control the electric heater according to the set values in the programming. The system indicates temperature from a microcontroller, and it will display it on the common cathode LCD. PID controller is a type of feedback control system commonly used in industrial processes to regulate variables such as temperature, pressure, flow rate, and speed[21,46]. The name PID stands for Proportional-

Integral-Derivative, which are the three terms that make up the control algorithm. Let's break down each component.

2.6. Conventional Proportional Integral Derivative Controller (PID)

As an important parameter in industrial manufacture and most household appliances and devices temperature is to be measured and controlled to reduce energy consumption work with dominant performance and precision of the devices and system. The PID algorithm calculation output is used to adjust the controlled object operation [34,51]. In the cooking appliances, varying heater power or the degree to which the power is supplied. The simplest and most used and practical controller is the on-and-off controller type[33]. Typically, the output takes a PWM signal, which satisfies the design specifications by adjusting the output control signal pulse duration ratio as required [27,41]. PID controller is a simplistic control for one parameter controlling model like temperature[32]. The feedback correction term is derived using separate gain values from each parameter sensor feedback control used in the loop to keep optimal operating temperature.

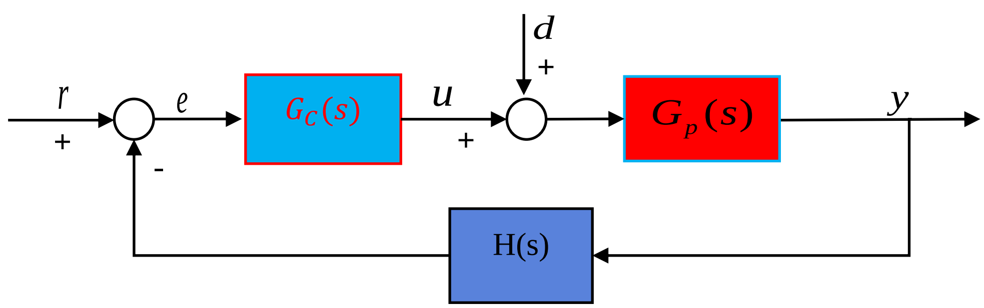


Figure 2.1. The conventional PID controller structure

Where r, e, u, y, H(s), G_C(s), and G_P (s) are set point input, error, controller output, feedback gain, plant output, PID controller, and plant transfer function model, respectively. The PID controller is the summation of three actions, namely Proportional, Derivative, and Integral, as shown in Equation 1.

$$G_C(s) = K_p(1 + \frac{1}{T_i s} + T_d s) \quad (1)$$

Where, K_p, T_i and T_d are called proportional gain, integral and derivative time, respectively. The PID controller tuning determines those PID controller parameters. The driving of the closed-loop transfer function for optimal set point and disturbance rejection is analyzed by setting the disturbance to zero[51]. The optimal set point tracking and reference input to zero for optimal disturbance rejection. Considering unity feedback gain H(s) closed-loop transfer function for optimal, set point tracking, $G_{yr}(s)$ and disturbance rejection $G_{yd}(s)$ are given in the Equations below.

$$G_{yr}(s) = \frac{Y(s)}{R(s)} = \frac{G_C(s)G_p(s)}{1+G_C(s)G_p(s)} \quad (2)$$

$$G_{yd}(s) = \frac{Y(s)}{D(s)} = \frac{G_p(s)}{1+G_C(s)G_p(s)} \quad (3$$

The closed loop transfer function has only one tunable element. This fact results in the following difficulty. In optimizing the set point response, disturbance becomes poor and vice versa. Some researchers provided two types of PID controller tuning methods, one for optimal disturbance rejection and another for set point tracking[52]. Those tuning methods are proposed for the first order plus time delay (FOPTD) model. The general structure of the FOPTD process model is given as;

$$G_p(s) = \frac{Ke^{-Ls}}{1+Ts} \quad (4)$$

2.7. Review of PID Controller and Heating System Modeling

Set point tracking and disturbance rejection are the most critical aspects of every process control application, with the conventional one-degree-of-freedom PID controller. However, it is difficult to achieve simultaneous set point tracking and disturbance rejection. This shows whenever the system set point tracking is optimized, the disturbance rejection response becomes bad and vice versa. This situation leads researchers to find alternative solutions in optimization.

The transfer function of a system provides the dynamic behavior of the process being controlled. This is used to apply the controller. However, the heating process system dynamics depend on the condition in which they are being operated, which presents a challenge for modeling[53]. Identification solves such problems in transfer function modeling.

System identification is part of system control to determine the plant's physical characteristics, based on real-time measurement or experimental data. The main controlled parameter in the heating system is the temperature, the thermocouple is used to sense the closed-loop response of the electric oven. Temperature control experimental setup for the heater and identifies model by applying a step input to Solid-State Relays (SSR) connected to heater coil for power regulation

CHAPTER 3

Method and material

In this section, discussions about the procedure of the study and the material used. Method to collect temperature profile of EIBM, experimental data used to design controller. The design and development of an electric mitad controller, based on the required surface temperature of mitad to bake injera. The design procedure in this work is based on rating the power of locale-made electric mitad. The controller was designed using a microcontroller and electronics devices combined with sensors all the materials used to develop the data logger and controller are listed in table 2. MATLAB Simulink software is used to model and validate the system's mathematical model and temperature response. Also used for the controller to estimate constants of PID parameters using tuning tools. The controlled and uncontrolled experimental test results and average energy and time reduction per injera baking and the system temperature bandwidth were compared in percentage.

3.1. System Modeling and Parameter Estimation

In this section locally made electric Mitad having 57 diameter and average power consumption of 3.62 Kw is taken as a controlled object. To estimate its temperature parameter, consider the output process variable. An experimental setup prepared with hardware and software components. A custom-developed data logger was used to store and measure temperature data. The measured data were used to determine the temperature profile, with load and without load of EIBM. The data will be analyzed using software package tools. To observe the correlation between temperature and input electric power of EIBM, this study. The parameters were estimated, using measured data to generate a mathematical model of the plant the PID controller. The design and development of an electric mitad controller is depend on the surface temperature load profile of the mitad that used to bake injera. The design procedure in this work depends on the rating power of the locale-made electric mitad and experimented temperature test data. The controller was designed using a microcontroller, power electronics device, and temperature sensor to measure and compare the actual plant output variable with the required set point. To regulate, power input using Triac as an actuator, while receiving signal from the microcontroller and executes the task.

3.2. Material

The following software and hardware components are used in this research, MATLAB 2022b to the simulation and tuning of the controller. Arduino software, IDE to sketch the program Cod for, 8051 microcontrollers, K type thermocouple temperature sensor. A developed data logger, locally made EIBM, infrared thermocouple, and electric energy logger are used to set the experimental setup.

Table 2. Materials used to develop and test the controller

Electric mitad	Local-made electric mitad uses a resister heating element in the plant to be controlled, the controlled variable is surface temperature.
Microcontroller (MC)	Use to receive actual analogy temperature read of the top surface of mitad while to measure temperature profile by sending an instruction to the power electronics circuit to control the supply power. Based on the feedback response using PID on and off the system.
Solid state relay (SSR)	Used as an actuator to switch on and off the AC power supply of the plant or Mitad, based on the instruction send from microcontroller
K-type thermocouple sensor	A Thermocouple is a sensor used to measure the temperature of the mitad by putting it at two points of mitad.
LCD liquid crystal display	To display the actual top surface temperature from the thermocouple by converting an analog signal to digital, using Maxx6675 module.
SD card	To store the temperature value of the thermocouple sensor reading with the controlling circuit board and power supply for the microcontroller.
Energy logger	Use to measure the supply input power and voltage into mitad
PCB	Used to develop controller circuit prototype and temperature data logger.

3.3. Experimental Setup

The parameters of the controller model are estimated from the actual response of the plant. Then using first order plus time delay (FOPTD) Constance. The input power and process variable (or temperature) output data are measured experimental. The method of data collection was performed, using a developed temperature data logger in the particular study. Microcontroller power electronic device, sensors, and software programming code combine to read and store step response data of EIBM. The required components, their configuration overall experimental setup structure are shown in Figure 3.1, below. The description of the selected component used for this research is explained in this section.

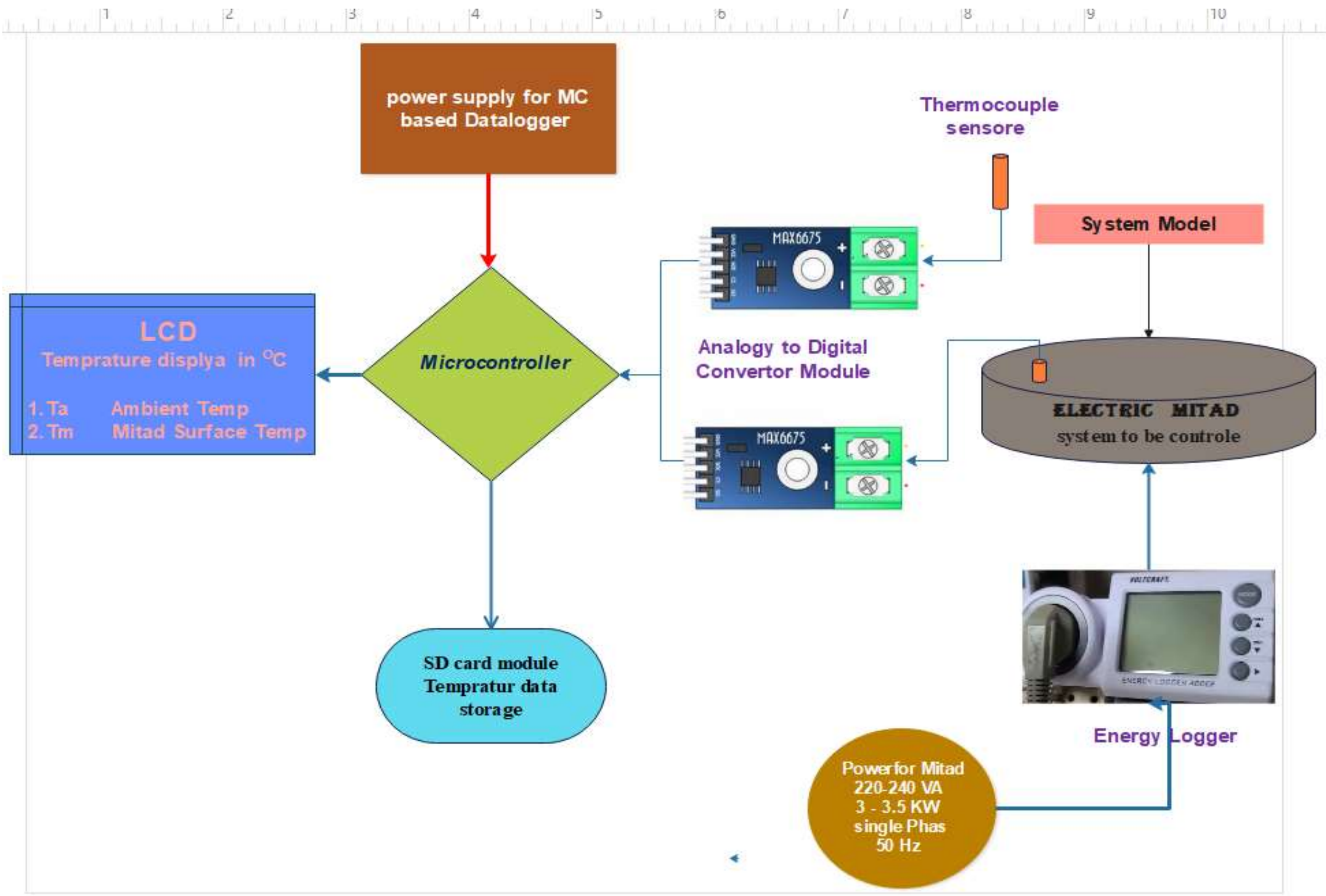


Figure 3.1. Schematic diagram of an experimental setup to measure temperature and energy

The continuous power supply of the existing electric mitad operates for 1-2:30 hours. While at the time of injera baking in most households. Consider the existing EIBM used in the community as a plant. The energy consumption of mitad and its voltage supply fluctuation, parameters are considered and measured in the input. The most required output process variable is temperature. The developed temperature data logger is designed to measure, the temperature of mitad at two points in each five-second interval up to the end of the baking process.

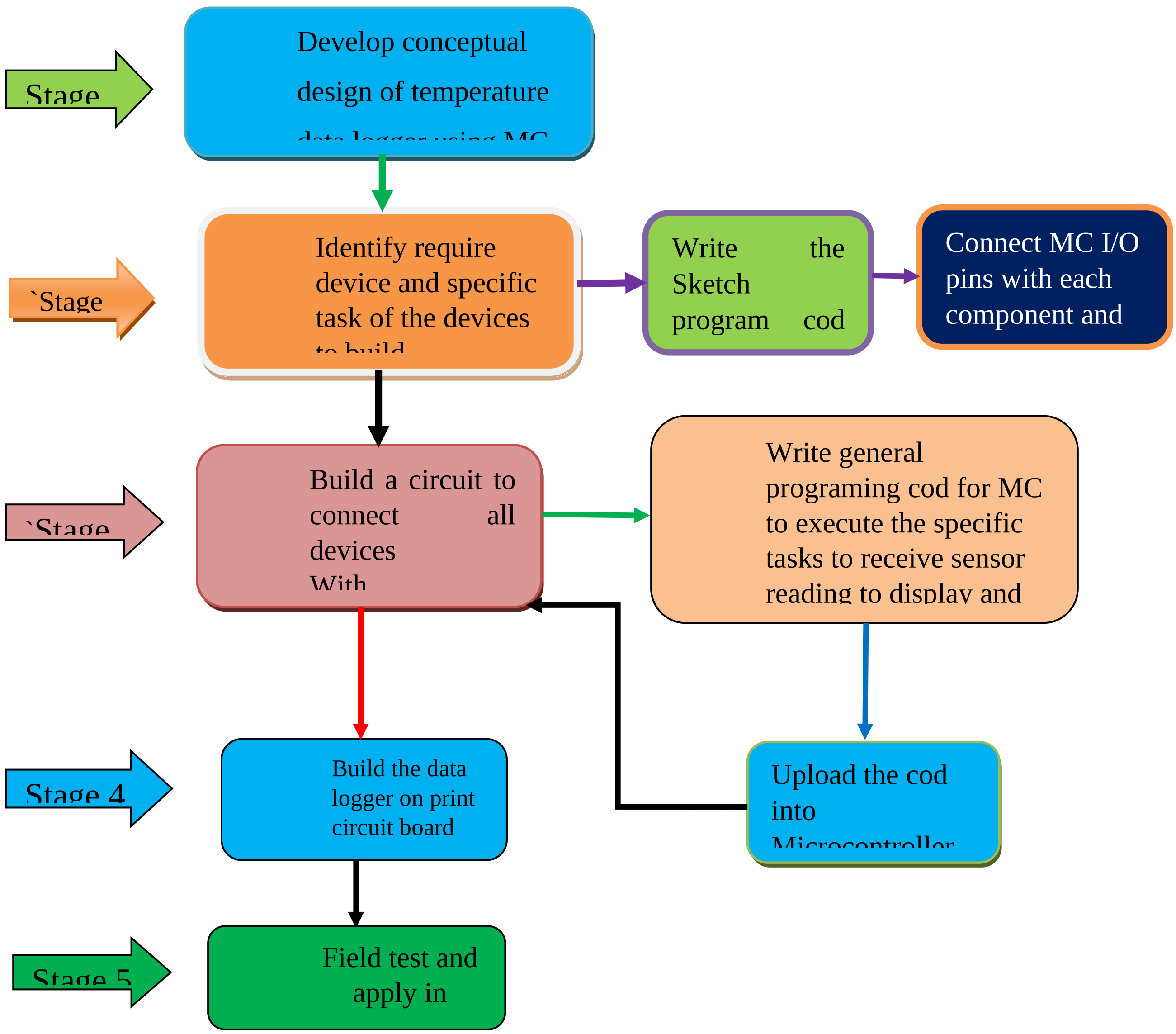


Figure 3.2. Schematic diagram of custom temperature data logger development stage

3.4.1. Energy logger

The first experimental setup is prepared to collect the process baking temperature profile and energy consumption of locally made EIBM. Voltcraft energy logger is used, to measure the energy consumption of the plant and also to measure the line voltage supply, and the current that the EIBM generates. Then it stores the full electrical data into the SD card. The device is connected to one side from the line voltage and the other to the load or electrical mitad.

3.4.2. Temperature data logger

An infrared thermometer is used to calibrate and measure the surface temperature of mitad while reading and comparing values with developed data logger temperature reading values, the measurement taken during each experimental test. Two K-type thermocouples are fixed at the center of the mitad cover and the edge of the top surface Mitad, the setup is shown in Figure 10, and the output terminals are connected to the MAX6675 analog-to-digital converter module [54]. The module terminals connect to the host device input and output pins Arduino Uno electronic circuit used. Then signal conditioning and processing, are executed in 8051 microcontrollers. Finally, the processed signal is sent from Arduino Uno to the configured device to execute action, for a developed data logger. The sketch code written by IDE is uploads in the logger by 9600 serial communications.

3.4.3. Components of the developed Temperature data logger

- **Maxx6675 module**

The Maxx6675 module is a popular integrated circuit (IC) used to convert analog temperature readings from K-type thermocouples into digital form. The module typically consists of the Maxx6675 IC, along with supporting components like resistors and capacitors, all mounted on a small circuit board for easy integration into projects[55]. Also, I/O commonly found pins in the module and their uses such pins are VCC pins are used to supply power to the module[48]. It typically requires a voltage in the range of 3V to 5V. ground pin GND this pin is connected to the ground or negative terminal of the power supply. It serves as the reference point for the module's operation[56].

Serial Clock (SCK) This pin is used for synchronous serial communication between the Maxx6675 module and a microcontroller. It is used to synchronize the data transfer between the two. SO (Serial Data Output) The SO pin is used to transmit temperature data from the Maxx6675 module to the microcontroller in this research experimental setup. Through this pin sends out serial data in a predefined format using SPI (Serial Peripheral Interface) communication protocol [36].

CS (Chip Select) The CS pin is used to select the Maxx6675 module for communication, with a microcontroller. So the two SC pins of Maxx6675 connect in digital pins 5 and 3 on the Arduino Uno board. Positive and negative terminals are the input for connecting the thermocouple. The thermocouple typically consists of two different metal wires joined together at one end, and these wires are connected to this module. The temperature difference between two junctions of the thermocouple generates a voltage. Then Maxx6675 module converts the generated voltage in the thermocouple into digital form.

- **Liquid crystal display**

One liquid crystal display (LCD) is used to display the temperature reading of the two thermocouple measured values, while observing the states of the temperature shown in Figure 8 b. SD card is used for data storage in the developed data logger, to store measured temperature data along with the time. So, the SD card module is a peripheral device used to interface with a microcontroller. It provides a convenient way to read from and write on SD cards embedded. In our study used only to write the value of temperature on the SD card and used to analyze the stored data later to study the temperature profile characteristic of mitad.

- **Real-Time Clock (RTC) module**

This module is used to record the time when the temperature is read along with its measured value of the data logger. RTC modules typically include a combination of a clock chip and backup power source, while communicating with a microcontroller shown in the Figure below.

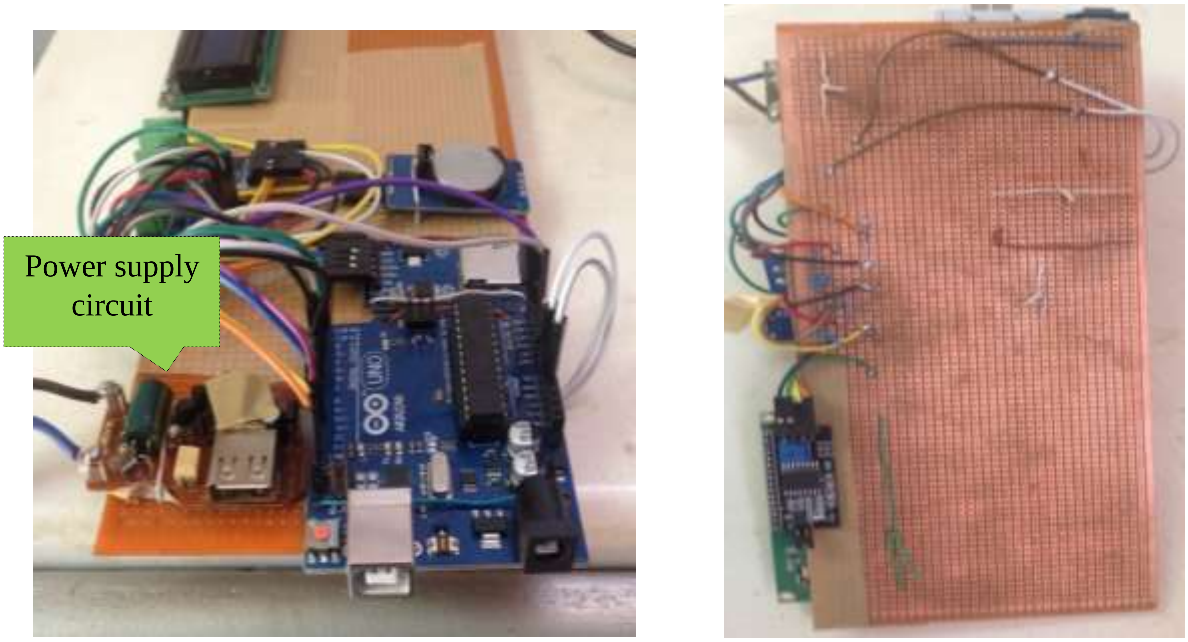
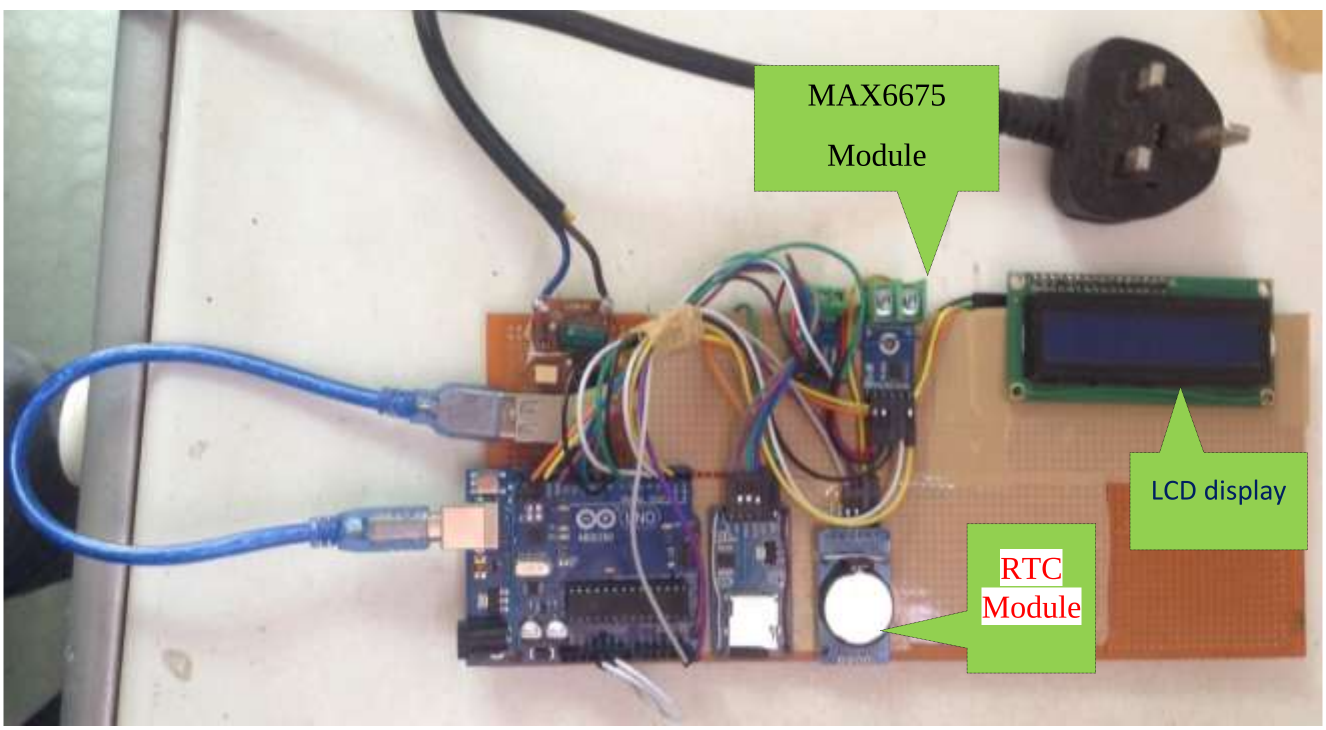
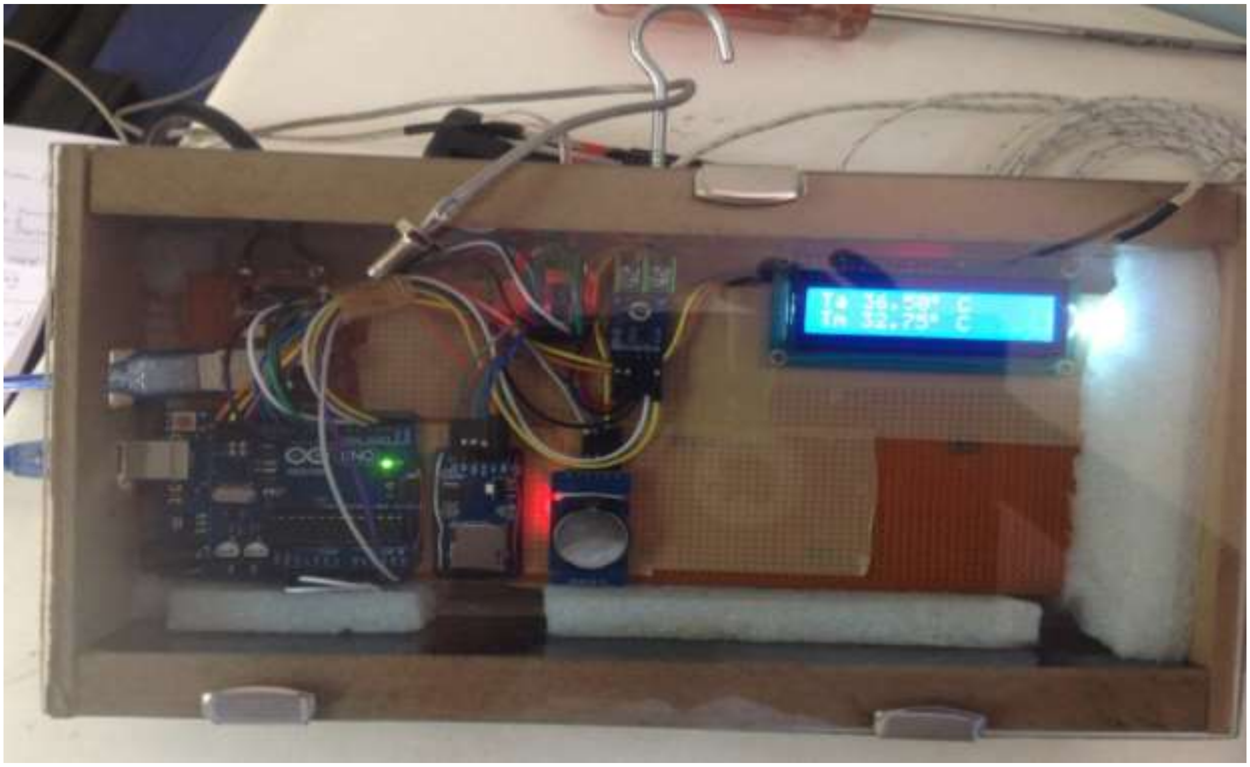


Figure 3.3. Power supply circuit for microcontroller and power supply system for modules.



(a)



(b)

Figure 3.4. Developed microcontroller base temperature, data logger

3.4.4. Methodology

As shown in Figure 3.2, the block diagram summarizes the steps that followed to achieve the controller design. Based on temperature characteristics experimental value of injera baking mitad EIBM, and its working temperature range were used to design the controller. Experimental data is used to estimate parameters, process characterizing and determine the mathematical model, during model validation. In this study experimental setup of hardware and software integration and a costume temperature data logger was developed to record, display, monitor, and export the step response into an Excel spreadsheet.

Then FOPTD transfer function is estimated, and the generic model parameters of the controlled object from measured data. Graphical method used to estimate model parameters. The supper guesses the value of PID controller parameters estimation combining, the automatic Ziegler Nichols tuning method to controller parameter tuning method for simultaneous set point tracking and disturbance rejection response. Finally, MATLAB 2022b software implemented the proposed on-off PID controller and compared its energy performance to none controller EIBM.

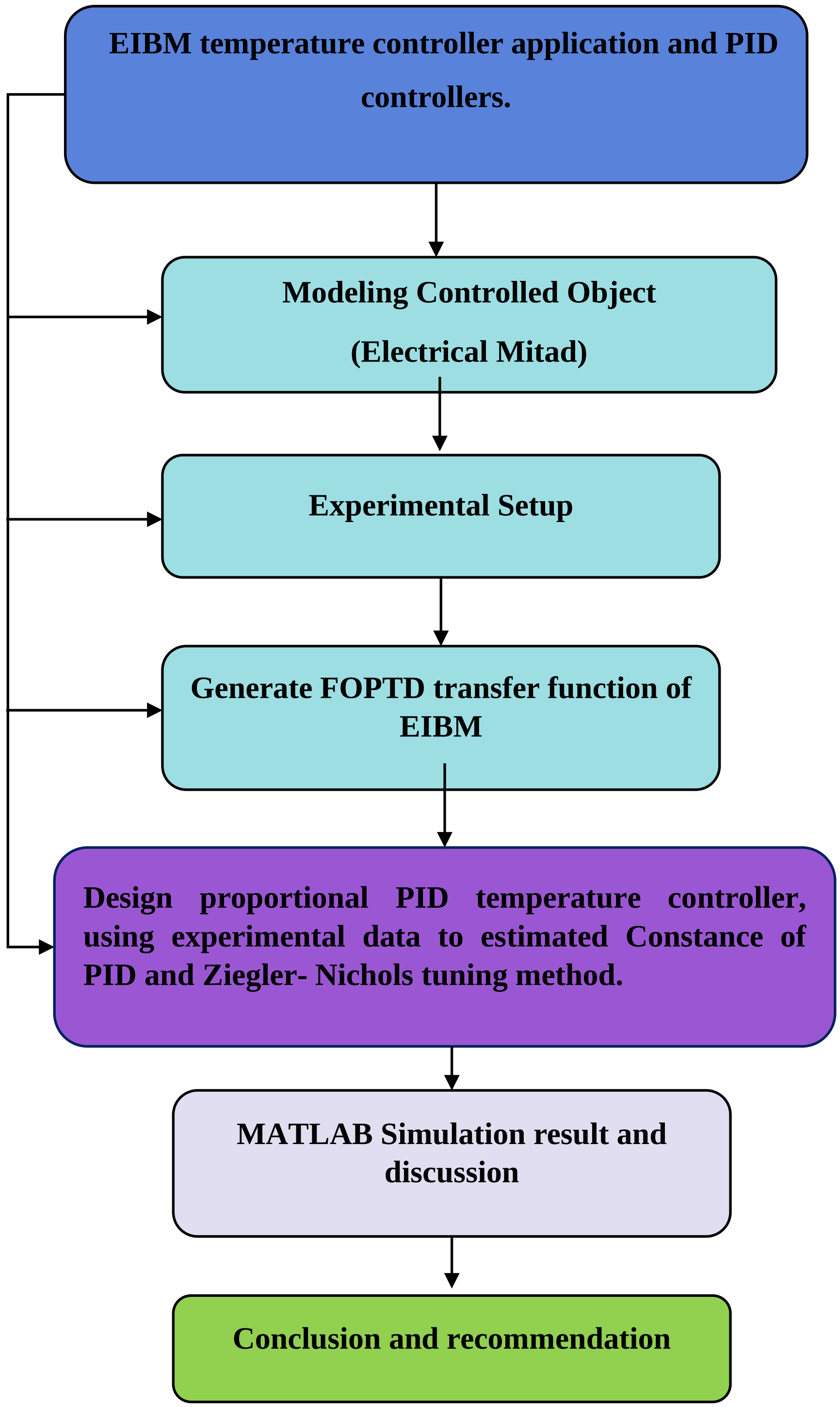


Figure 3.5. Methodology block diagram

3.4.5 Modeling of the Controlled Object

Figure 3.6, represents the block diagram of the proposed temperature control system. The error between the reference input (set point) and the Injera Cooking plate output is an input to the PID controller design in this section. The controller generates the required control input signal [57,58]. A Proportional Control Solid State Relay (SSR) generates an output power in response to the controlled input signal as an electrical power Actuator. The power Actuator operates with a limited controlled input signal because it is necessary to limit the controller input signal for protection.

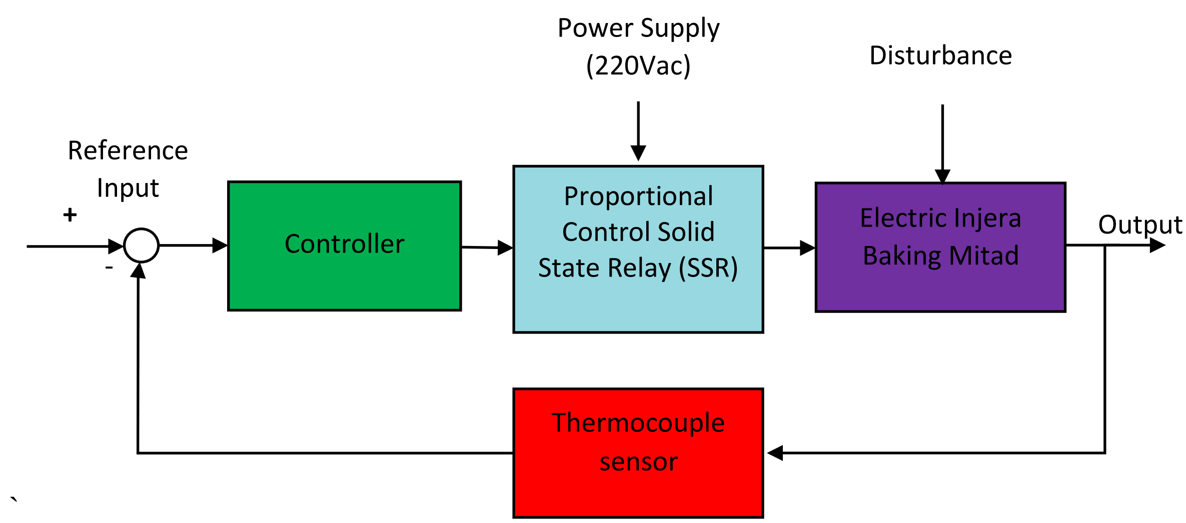


Figure 3.6. Block diagram of the proposed temperature control system

The control system shown in the figure above has two parts, a controller and a controlled object. The controlled object consists of the electric power Actuator and Injera baking Mitad and sensor

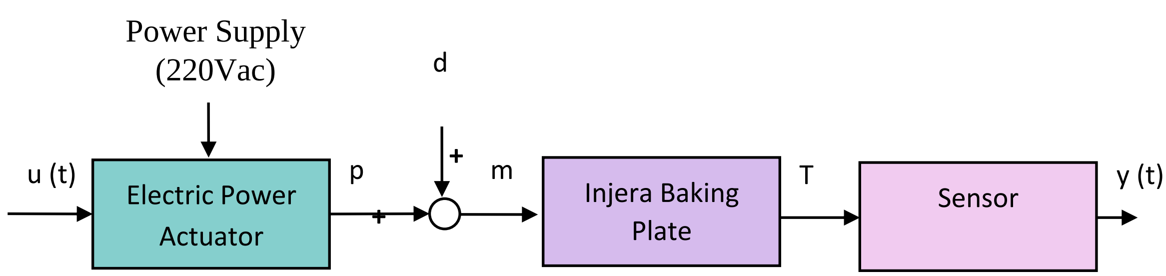


Figure 3.7. Block diagram of the controlled object

In Figure 3.7. Show that u (t) denotes the control input, p power Actuator output, d disturbance, m power applied to the Injera Cooking plate, T the temperature of the cooking plate and y (t) the temperature output.

3.4.5.1. Electric Power Actuator

The electric power Actuator plays the role of triggering the electric power supply. It controls the baking temperature by regulating the supply voltage, 220V AC input signal V_s in response to the controller output signal. Through the Study proportional phase angle digital voltage solid state-relay (PPADV-SSR) used as a power Actuator [59]. PPADV-SSR is a type of Solid-State Relay (SSR) that provides proportional power to the load, based on values of an analog signal applied to 0 to $10V_{dc}$. In the PPADV-SSR[33], the input signal is controlled by triggering a pulse of output at a particular phase of the input modulation cycle, at the half-cycle in response to the 3-32 V_{DC} analog input signal Figure 3.8. Shows phase angle control at the triggering angle phase.

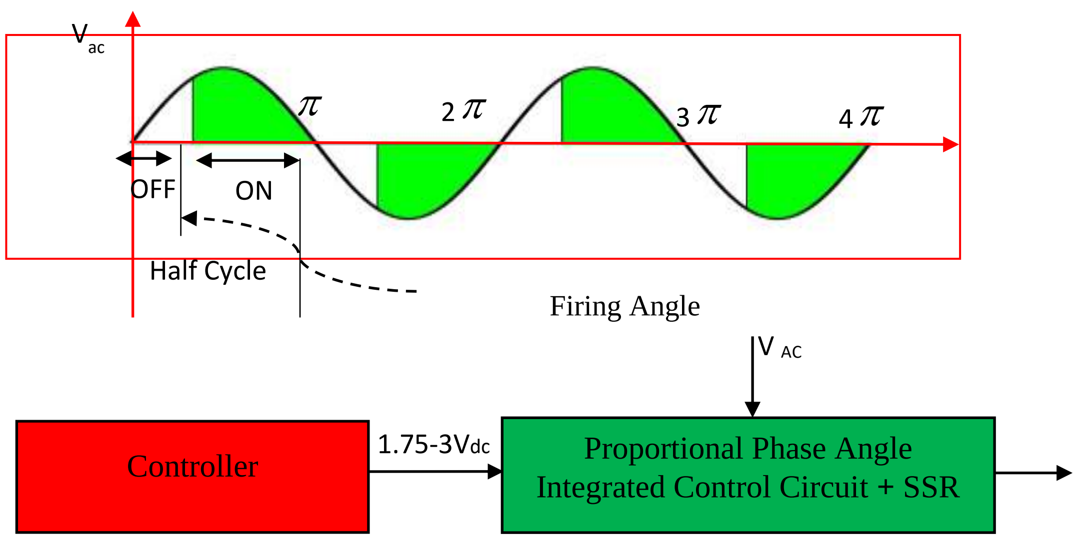


Figure 3.8. Proportional Control Phase Angle SSR

3.4.5.2. Introduction to solid state really

A Solid-State Relay (SSR) is an electronic switching device that switches a load of much higher power, by providing a small input signal, without having moving contact. In terms of operation, SSRs are not very different from mechanical relays that have moving contacts. SSRs, however, employ semiconductor switching elements, such as thyristor, Triac, diodes, and transistors.

The optical semiconductors are called photo couplers to isolate input and output signals. The photo coupler changes electric signals into optical signals and relays the signals through space. Fully isolating the input and output sections, while relaying the signals at high speed. Also, SSRs consist of electronic components with no mechanical contacts. Therefore, SSRs have a variety of features that mechanical relays do not incorporate. The greatest feature of SSRs is that SSRs do not use switching contacts that will physically wear out and damage due to sparks. So, to control the electric mitad, in this study proportional phase angle photo couplers SSR was used. The working principle and the circuit schematic diagrams is discussed below.

1. The input device (switch) is turned on.
2. Current flows in the input circuit of the photo coupler and an electric signal are transferred to trigger the output circuit.
3. The switching element in the output circuit turns on.
4. When the switching element turns on, load current flows and the electric mitad turns on.
5. The input device (switch) is turned off.
6. When the photo coupler turns off, the trigger circuit in the output circuits turns off, which turns off the heating element.
7. When the switching element turns off, the power supply for EIBM is also off.

In the relay has four terminals labeled 1, 2, 3, and 4. The first two terminals (1 and 2) are connected to a load or IEBM of higher power to control, and the other two terminals (3 and 4), are connected to a microcontroller (input). The input signal (input) of the relay should be 3 to 32 V (DC), which means that the relay will turn on if the voltage between the plus and the minus is within that range. The actual connection is the minus side connected to the GND side, and the positive voltage to the plus side is shown in Figure 3.9, b. Also, there is a red LED on the relay that visually displays the status of the relay (it lights up when it is on). The basic component of this relay is the so-called TRIAC. A TRIAC is a semiconductor component that can control alternating current [55]. It will conduct when the control electrode is induced and stop when the control electrode is turned off and the current flowing through the TRIAC falls below a certain level.

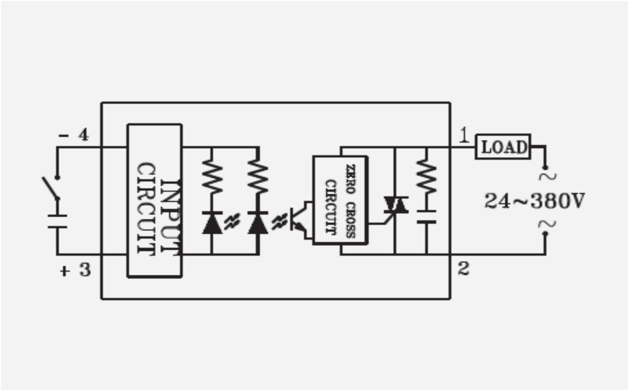


Figure 3.9. Schematic diagram of SSR electric circuit [24]

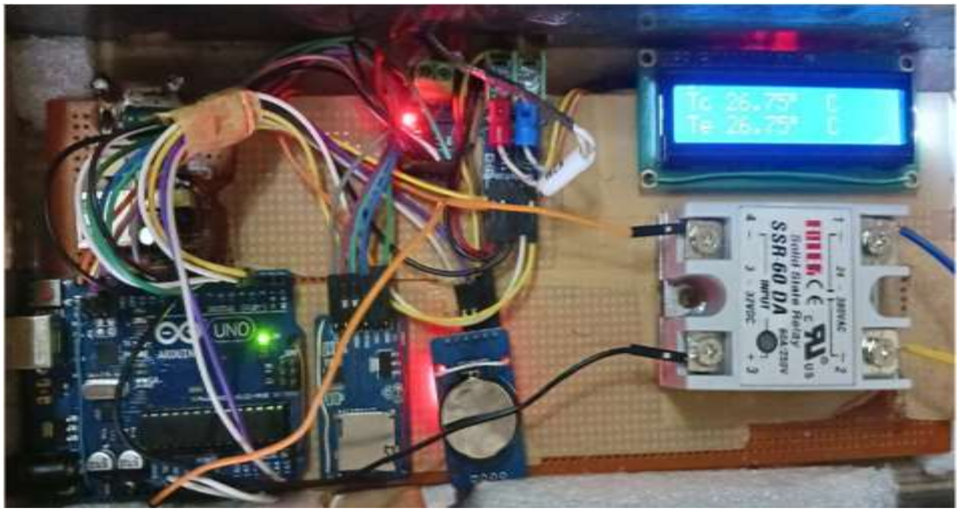


Figure 3.10. Developed temperature controller for EIBM

The control side is optically isolated from the output side of the load so the combination of controlling the relay with a microcontroller is possible. When it gains an excitation signal to the control side, an LED within the optical insulator will light up and trigger the control side of the TRIAC. On the control side of the TRIAC, there is also a circuit that detects the zero point of the AC voltage, as shown in Figure 3.10, above.

3.4.5.3. Control Methods of SSR

On-and-off control is a form of control in which a heater is turned on and off by triggering SSR gate with a very small direct current voltage supply. On and off in response to voltage output signals from a temperature controller, to control the heater if it is turned on and off at intervals of a few seconds over several years**.** phase control output is changed every half cycle in response to the current output signals in the range of 4 to 20 mA from a temperature controller. Such types of control are possible for high-precision temperature controllers used widely with semiconductor equipment. The thread type of controlling method is zero cross-control. Which determines the on/off status of each half cycle. A waveform that accurately matches the average output time is output. The accuracy of the zero cross function is the same as conventional zero crossing controller. With conventional zero cross control, however, the output remains ON continuously for a specific period. Whereas with optimum cycle control, the ON/OFF status is determined each cycle to improve output accuracy.

A proportional power controller is similar to standard ON/OFF power. It switches the power of an AC load. However, proportional controllers provide a percentage of AC power to the load in direct proportion to the analog input signal applied on the input terminals of SSR [25].

Through this study, 1.75-32Vdc analog voltage input range receiver signal type SSR is used shown in Figure 3.9. Analog input voltage is. The supply power from the source provides a percentage of AC power to the load (EIBM). Based on the equivalent to the percentage of the analog input signal sent from the MC. The proportion of the power controller input and output applied in this study is shown in the table below. 5Vdc is applied to the input of a proportional power controller with a 1.75-3V_{DC} input setting, then the output will provide 0 % power to the load.

Control Input (0 -3V_{dc})	0	0.75	1.5	2.25	3
Percentage Power %	0%	25%	50%	75%	100%

The selected SSR relay that withstands the AC load operates, the minimum of 1.75 Vdc, should supply to trigger at a minimum; while controlling phase angle, the triggering mechanism should be in the time domain. Based on the temperature bandwidth to turn off and on a relay within 60 seconds. The triggering action is created on the generated temperature so that four ranges are considered to track the set point temperature.

The reading temperature of the sensor is at the range of 200 and 196 ^{o}c Turn off the relay for 5.6 seconds and turn it on again for the next 20 seconds, the full cycle is considered as 60 seconds. The second temperature range is considered 191 and 195 ^{o}c turn off the relay for 3.7 seconds then on for the next cycle for 18 seconds while the full cycle is considered 60 seconds. The third temperature range is considered 185 and 190 ^{o}c turn off the relay for 2.5 seconds then on for the next cycle for 15 seconds while the full cycle is considered 60 seconds.

The last conditional temperature range is considered 180 and 184 ^{o}c turn off the relay for 1.5 seconds then on the next cycle for 15 seconds, while the full cycle is considered 60 seconds. This condition is programmed in the microcontroller to trigger SSR, which is equivalent to the control input and percentage power supply in 60 seconds shown in the proportional table above.

3.4.6. Injera Cooking Machine

Locally made electric Mitad is used in this experiment, to study temperature profile and process disturbance and to determine operating characteristics of temperature and baking time, as well as to observe the heat storage capacity of mitad. Generally, to study the process baking of electrical mitad and to evaluate energy consumption with and without a controller. While using experimental data to design, the controller for the plant EIBM. Figure 3.11, below shows the full experimental setup, used to measure the output temperature and input power or voltage supply for the EIBM.

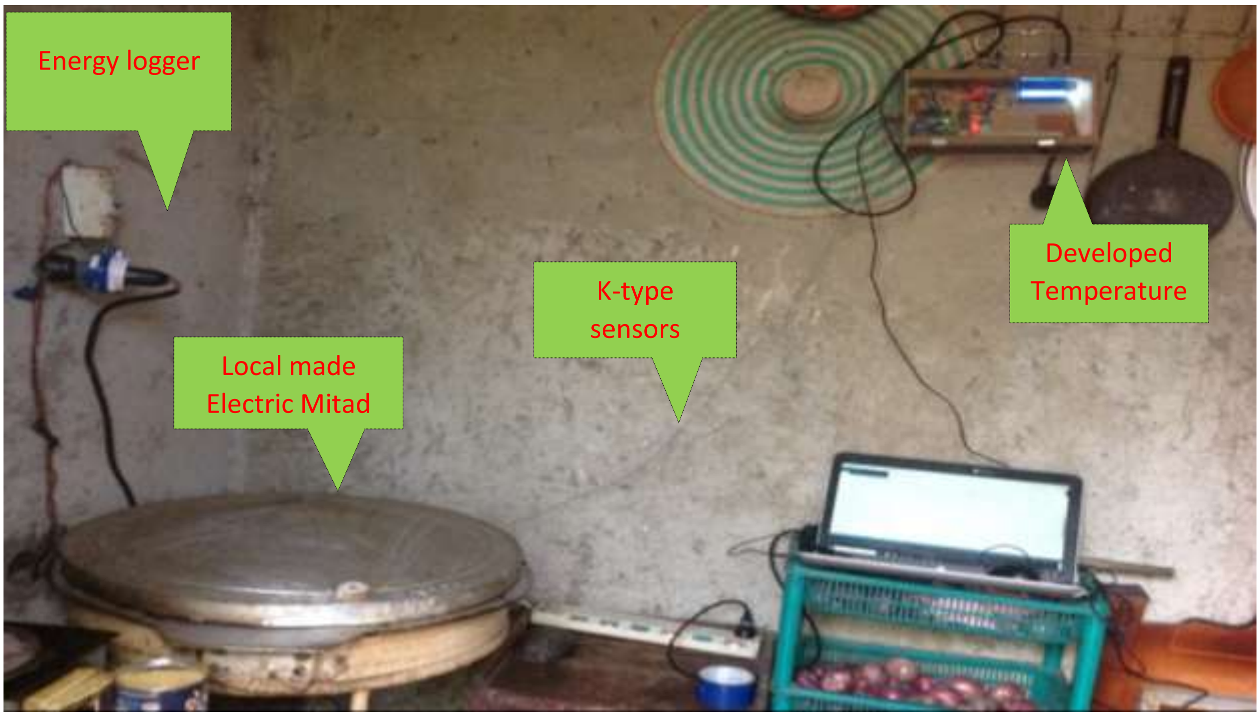


Figure 3.11. Experimental setup used to measure temperature and energy consumption

The temperature data measured from the first experimental test value is shown in Figure 3.12, the system states change with time. The temperature profile of the plant allows us to observe the baking process incidents. The system is initially at rest (steady state), while a change in the system independent variables input (or electric power is started (on)), the plant response after same times the dependent variables gradually change or grow. Finally, the system approaches a new equilibrium state or normal plant operating condition, we call that a new steady state. This normal operating baking temperature range is similar result, with previous studies on injera baking temperature, and literature works. However, actual experimented data indicate that there is an unsteady temperature profile at the desired operating temperature range from 180-197 ^{o}c.

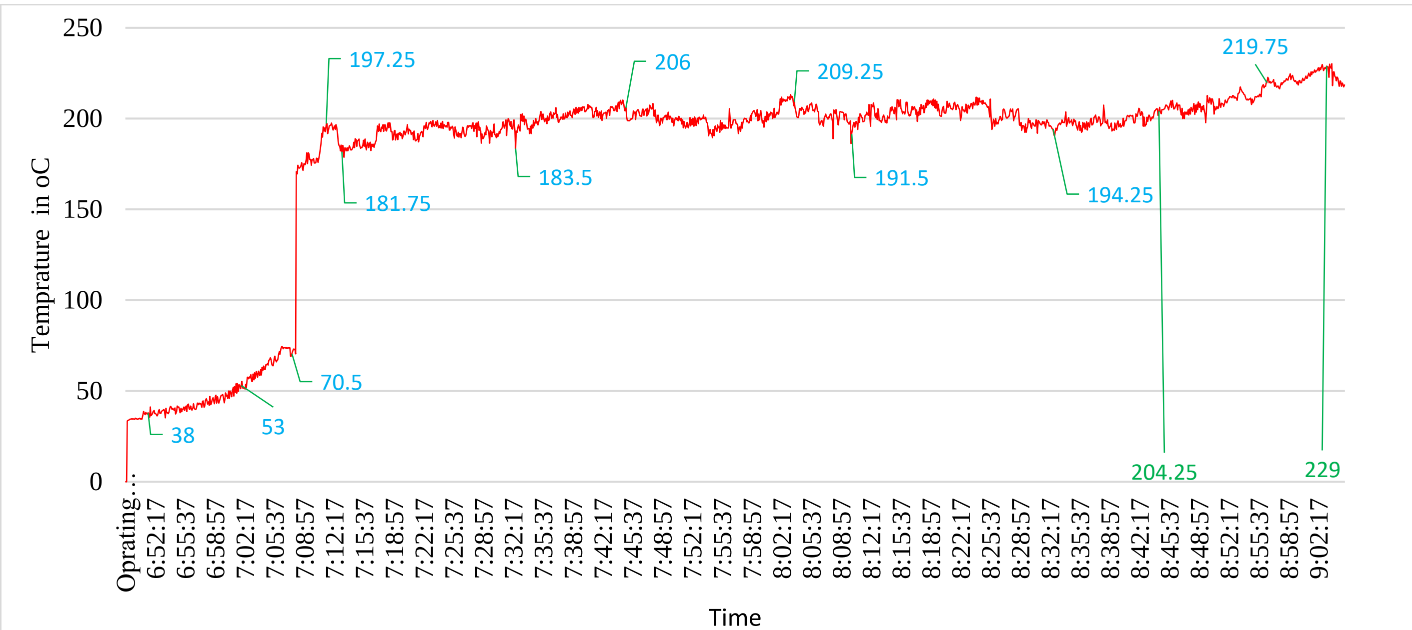


Figure 3.12. Surface temperature profile of Mitad at the first experimental test

In this experiment test the thermocouple sensor used for 2 hr. and 2-minute operation. Finally, the temperature rose up to 219 ^{o}c, which happened because of unloading conditions or without baking injera while switching off the power supply system. The temperature rises because there is stored thermal energy in the clay, this indicates that the material of mitad to be made has good thermal storage capacity. As shown in the figure above starting from 8:45:37-9:02:17 for around 18 minutes.

Figure 3.13. Experimental setup of K-type thermocouple sensors and energy logger on EIBM.

In the baking process of injera, through this experimental setup two k-type sensors are used to measure the surface temperate at two points, during the process of baking at the edge and center as portrayed in Figure 3.13 above, the point of the sensors is installed at the edge top surface of the Mitad and at the center inside cover of Mitad which is movable. During loading and unloading conditions or at the time of takeoff of baked injera and dispensing the dough, the center sensor measures the duration of baking of a single injera and the dynamic temperature profile during the loading and unloading condition. The temperature profile is shown in Figures 3.14 and 3.15 in zigzag form blue color. Operate for 4 hr. and 54 minutes and 2 hr. and 41 minutes respectively for the two tests.

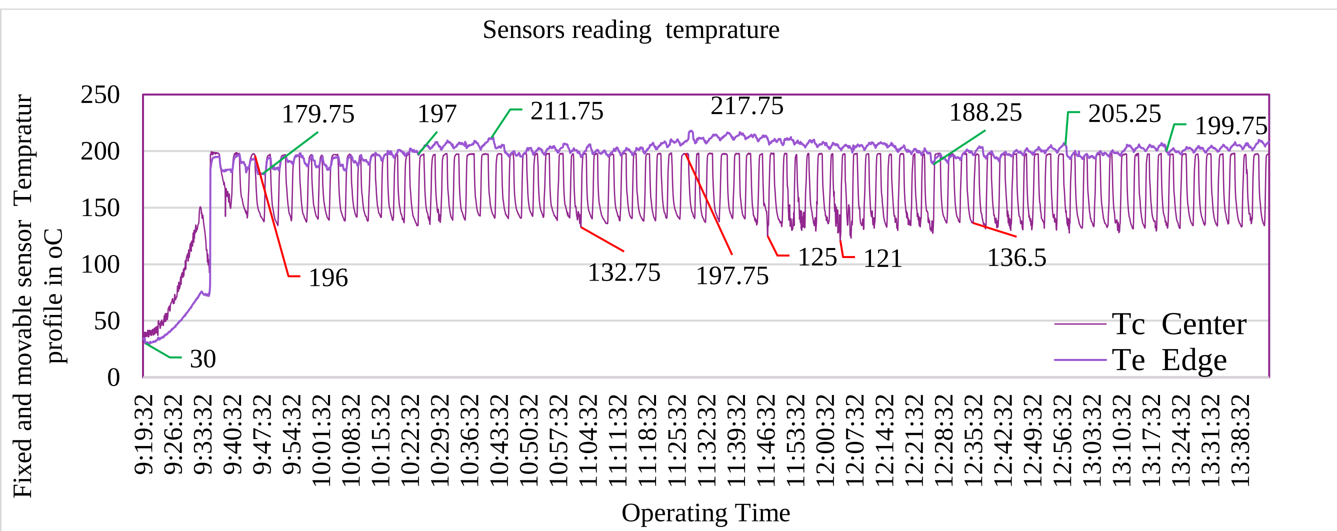


Figure 3.14. Surface temperature load profile of 2^{nd} experimental tests

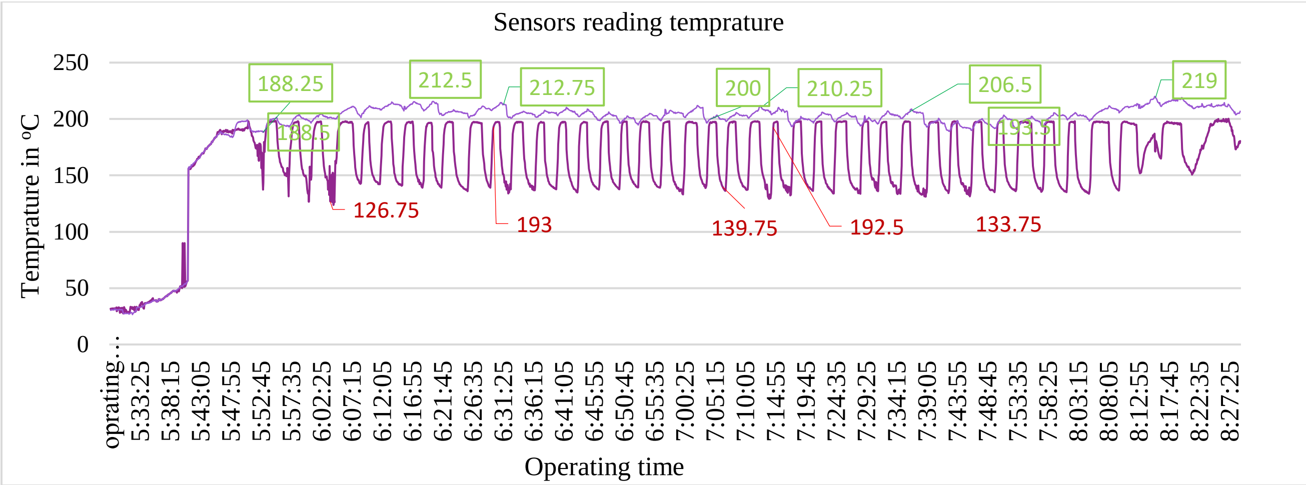


Figure 3.15. Surface temperature load profile of mitad 3rd experimental tests

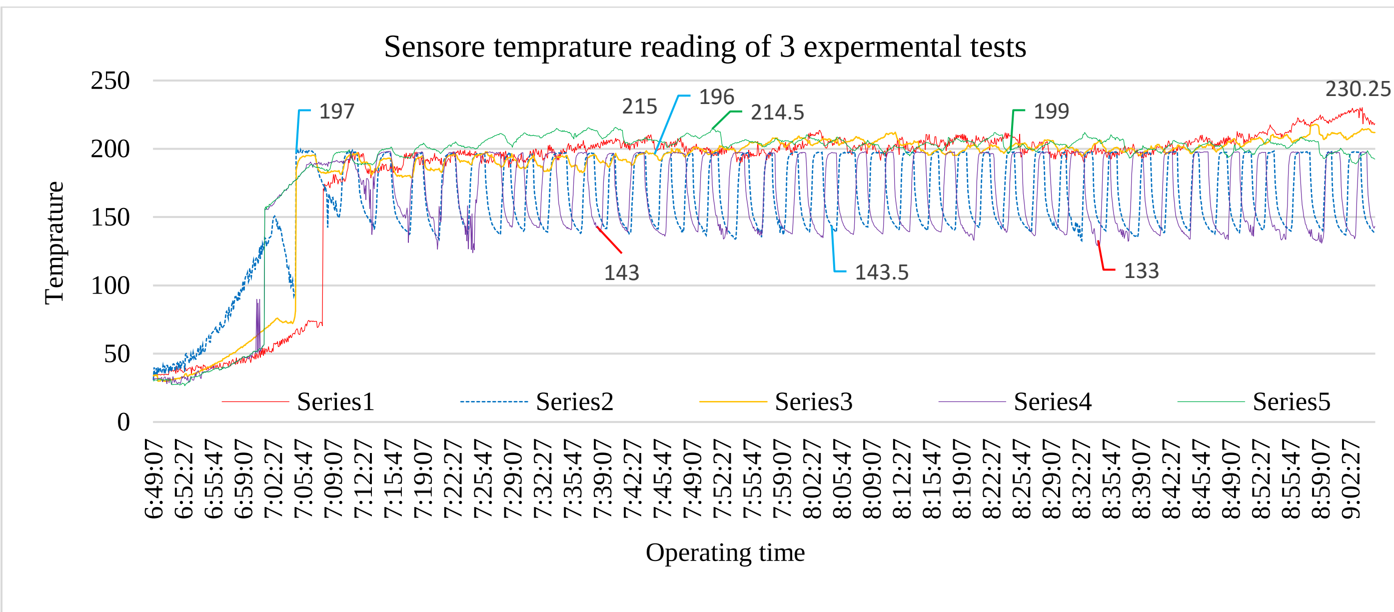


Figure 3.16. Temperature load profile of 3 different experimental tests.

The common minimum operating time temperature load profile of the three experimental test results is shown in Figure 3.16 for 2 hr. and 2 minutes operation, the result at the steady state baking temperature varies due to the line voltage fluctuation and other external factors.

System temperature response of mitad during opening and closing reading at load and unloading conditions. The temperature profile measured during the baking process indicates that there is a time that being ideal, but the energy or power is supplied. That is processing time bringing a baked injera and the next closing time of the IBM cover. The time duration is shown in the measured time, it takes the actual process response is shown in the figure below. Also, the experimental test result of the temperature profile of the first and third tests is shown in the table below.

Table 3. Surface temperature gradient during the baking process without controller

Test	Temperature Maximum in ^{O}C	Temperature Minimum in ^{O}C	Change Temperature in ^{O}C	Temperature Ambient in ^{O}C	Bandwidth in %
1	219.75	181.75	38	30	20.02 %
2	217.75	179.75	40	29.5	21.3 %
3	212.75	188.25	24.5	30	11.21 %

$$P_{band} = \frac{\Delta T_s}{T_{max} - T_a} x100$$

Figure 3.17, shows, the experimental baking process. The process temperature profile of the mitad is shown in Figure 20, taken at different times through the process. The profile looks u shape indicating two process conditions loading and unloading.

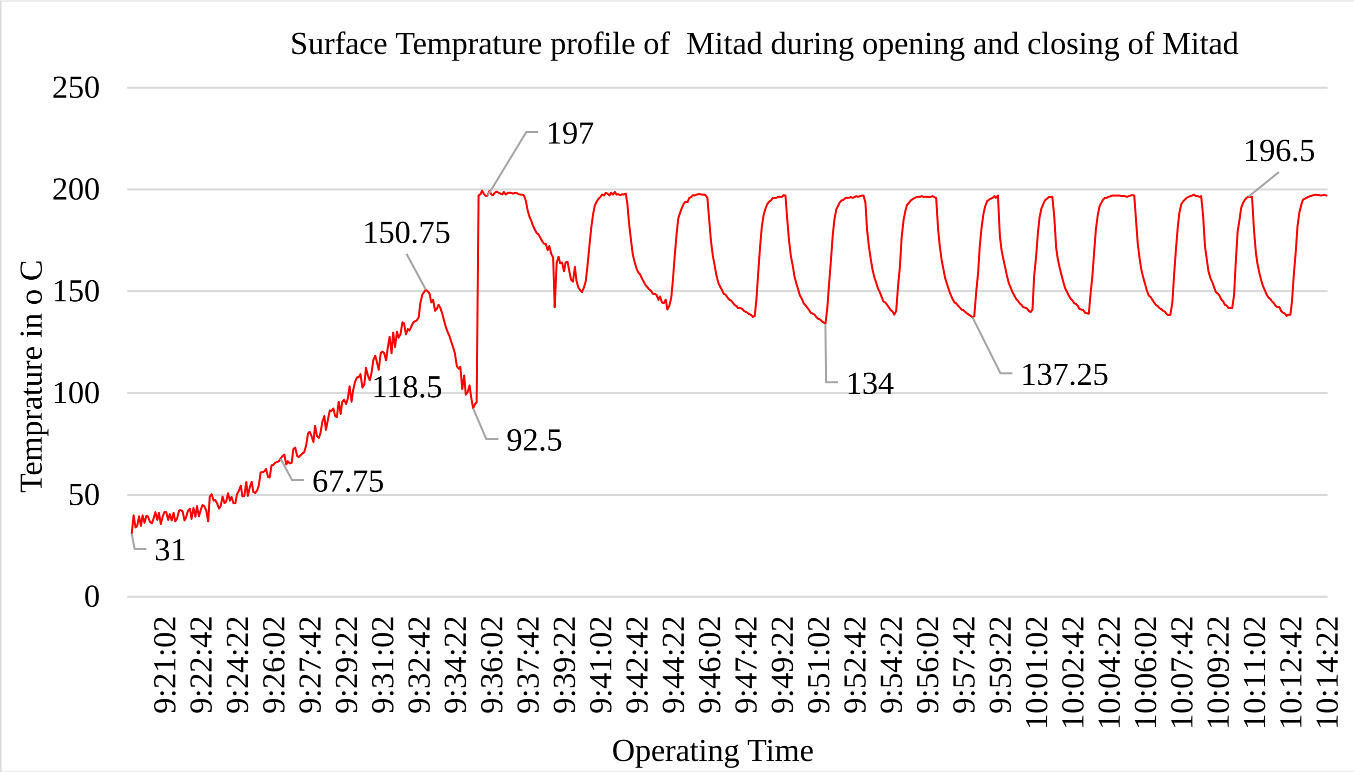
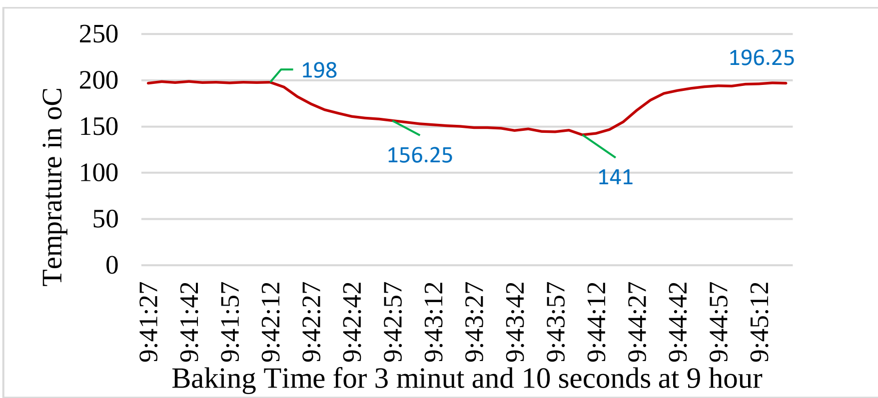


Figure 3.17. Surface temperature profile of mitad at load and unloading conditions

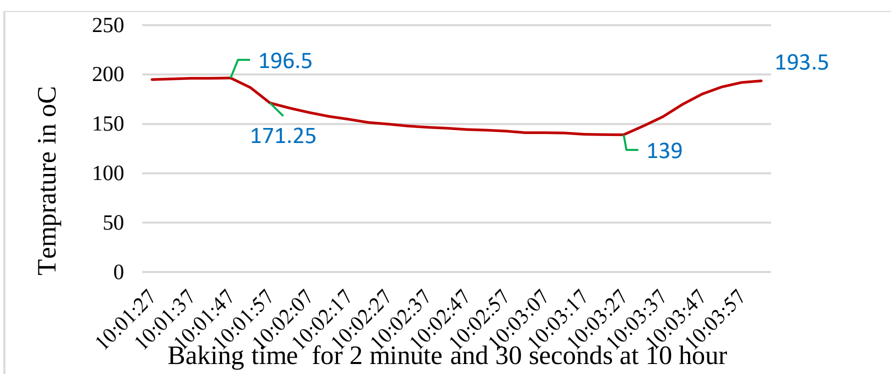
This shows the dynamic energy consumption behavior of mitad. With load conditions, the surface temperature of the mitad decreases and without load, it rises again, and it is important to determine the energy requirements for heating, heating rate, and time. The temperature profile is obtained from an experimental test to identify existing process disturbances.

At the time without load condition, the controller can take action, while using stored heat energy of clay or mitad. The temperature profile is measured by a thermocouple sensor attached to the cover of the mitad. To measure the center surface temperature of mitad, the immediate temperature of the poured dough and the baked injera surface temperature.

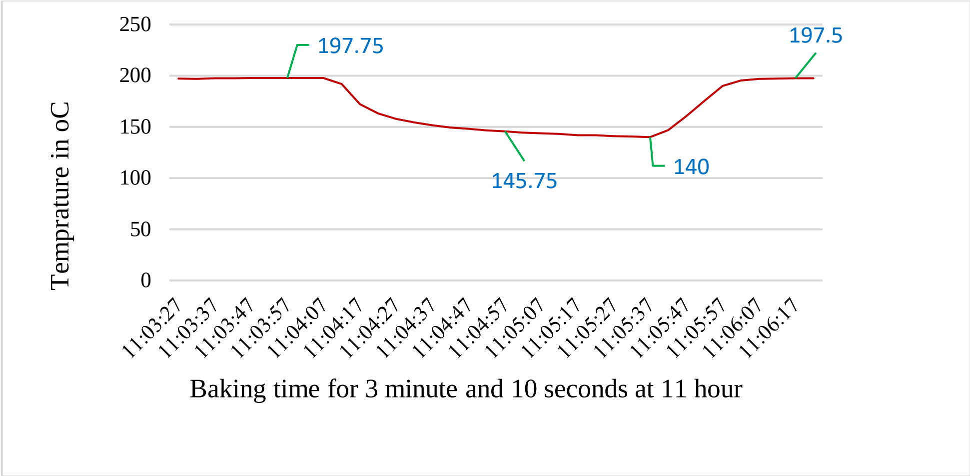
Figure 3.18. Injera baking Process with load and unload condition



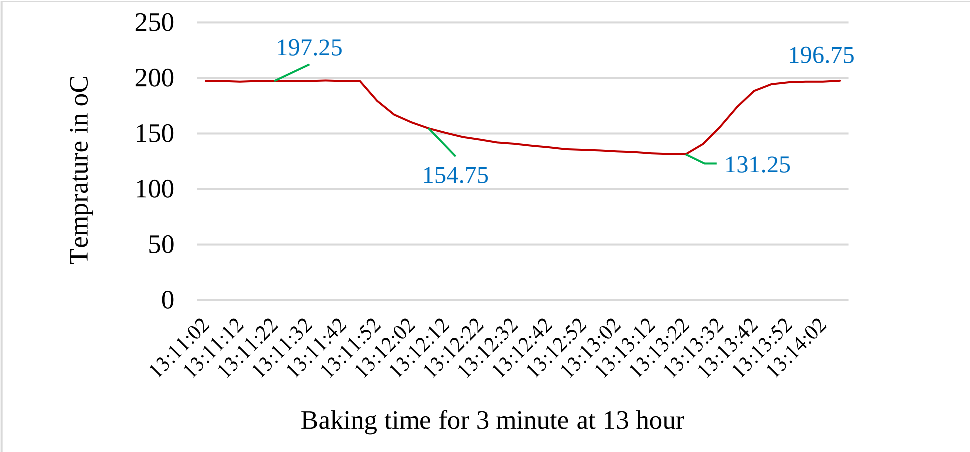
(a)



(b)



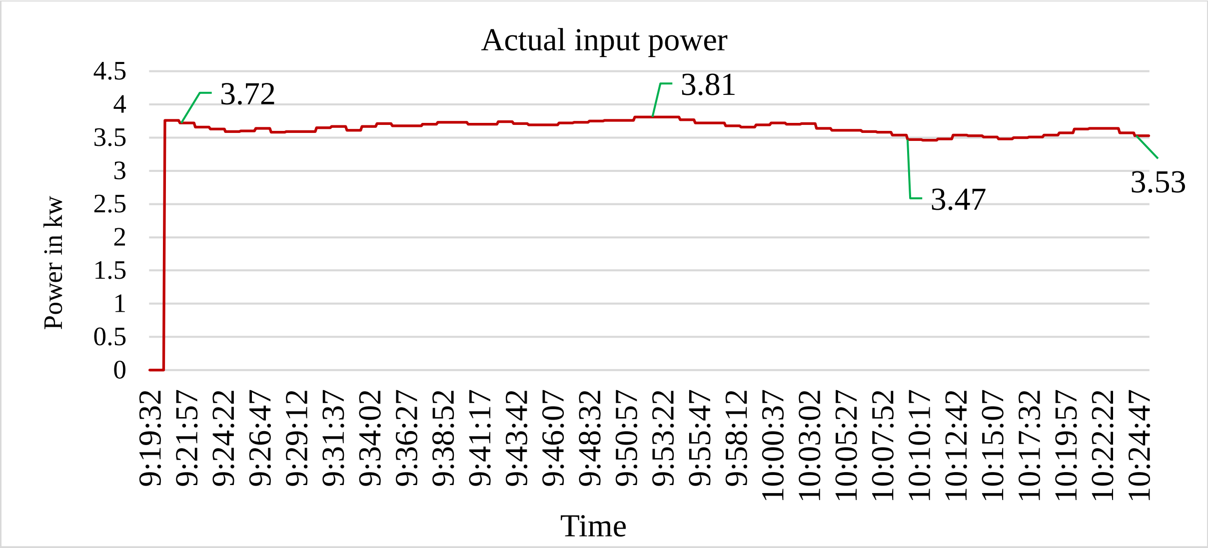
(c)



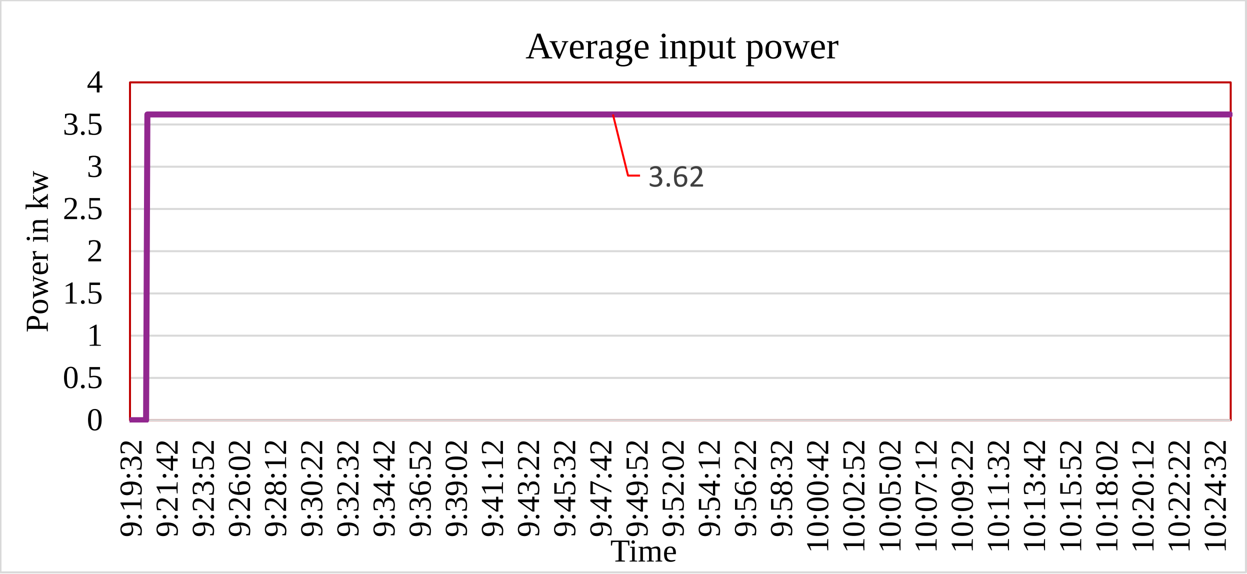
(d)

Figure 3.19. a, b, c, d, Load, and unloading conditions temperature profile of Mitad

Process for baking one injera using EIBM including diluting time of mitad top surface temperature profile, at loading and unloading conditions measured during opening and closing of the cover. In the experimental test observation, one injera is baked within 2-4 minutes. As stated in chapter two in the review section almost all the experimental results show the baking time is in the acceptable range for this particular EIBM.



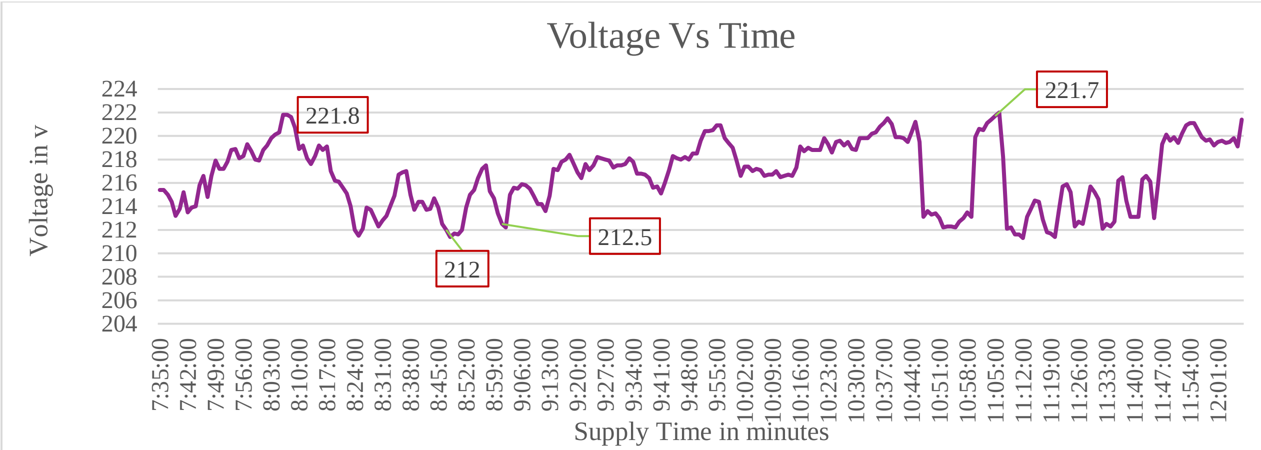
(a)



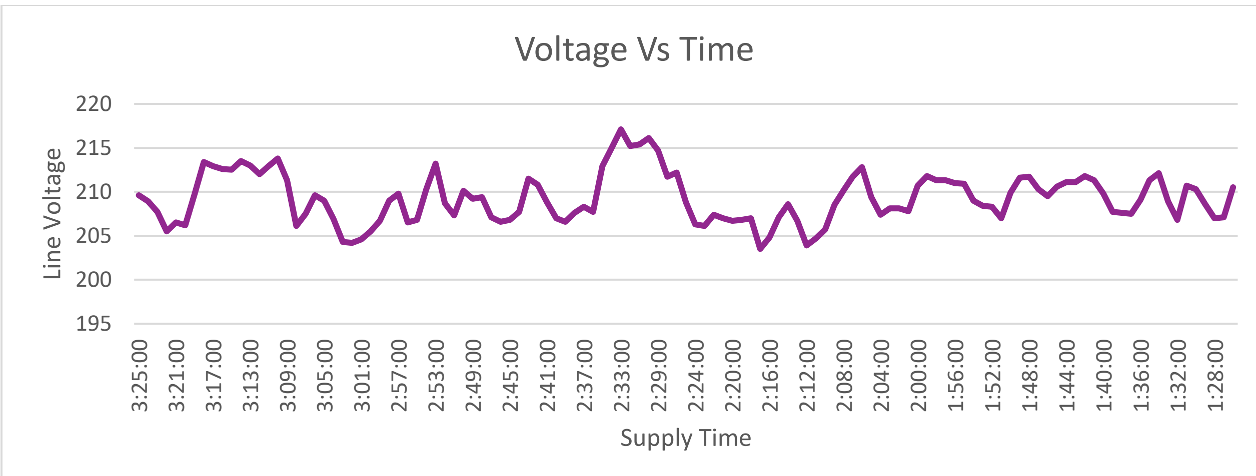
(b)

Figure 3.20. (a) and (b). Actual and average input power supply profile

The average input power supply is used to determine the process gain while estimating the constant of the First order plus time delay (FOPTD) transfer function of the system. the supply voltage from the distribution line varies over time. As a result, the input power of the plant is not constant. The measured supply voltage during the baking time using the energy logger is depicted in the figure below.



(a)



(b)

Figure 3.21. a, b. Voltage supply profile of 2nd and 5th experimental tests

Table 4. Experimental test of energy consumption operating time and number of baked injera

Test	Test date	Total baking time	Baking starts after	Number of baked injera	Energy consumption in Kwh
1	April 19	2 hr and 02 minute	19 minute	35	7
2	April 27	4 hr and 54 minute	16 minute	85	16.482
3	May 4	2 hr and 41 minutes	18 minute	41	8

The first test takes 2 hours and 2 minutes to bake 35 injera and consumes 7 kWh of energy. The average energy consumption per injera is the rate of total energy consumption and the number of baked injera. Also, the average time taken to bake one injera is considered as the rate of change of total baking time over baked injera.

$$Energy\ per\ injera = E_u = (P \times T) + \frac{E_S}{N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Energy per injera, E_u, Rating power of mitad, P, Baking cycle per injera, T, Startup Energy, E_s, total amount baked injera N [16]. The average energy consumption including the initial starting time of the uncontrolled mitad experiment test result is presented in Table 4.

Table 5. Average Energy consumption and time taken to bake one injera without a controller.

Test	Test date	Total baking time in minutes	Number of baked injera	Average injera baking time in minutes and second	Energy consumption in Wh	Energy consumption per injera in Wh
1	April 19	122	35	3:30	7,000	200
2	April 27	294	85	3:28	16,482	193.9
3	May 4	161	41	3:55	8,000	195.1
Average test result				**3:38**		**196.33**

The average baking time of the three tests is 3 minutes and 38 seconds and the average energy consumption to bake one injera is 196.33 Wh. This result is the experimentally measured value without controlling the baking process.

3.5. Mathematical model of the system EIBM

In this section, the mathematical model of the plant, from the external data is generated. The step response or output temperature profile of EIBM. The transfer function of the plant and constants of the transfer function including the plant gains are investigated in the next sub-sections.

3.5.1. Step response of locally made injera baking mitad

The experimental input and output measured data from locally made electric mitad. The energy consumption of the plant is measured in Kw, using an energy logger. Input and output profile curves are shown in Figures 3.19 and 3.20. The response PV of the system is the surface temperature of mitad, while the measured surface temperature load profile is shown graphically below.

First order transfer function with time delay plant model

To determine the first-order transfer function constants (gain, time constant) and time delay from experimentally measured data, typically used input-output data from the energy logger power in kw, measured with time, and the output parameter is the top surface temperature of electric mitad, that process variable recorded using developed microcontroller-based temperature logger. In this study, the following procedure was implemented to determine, the first-order linear system transfer function with a time delay to the proposed plant of electric mitad. To determine the optimal constants used to implement. Ziegler- Nichols PID tunning method used to determine P and I constants.

To determine the constants of the FOPTD, the graphical method used the input and output versus the time graph of Figures 3.14 and 3.20. The input and output data versus time plot were used to for mathematical modeling using a simple graphical method. The input is typically denoted by u (t) the output by $y\ (t)$ at a function of time.

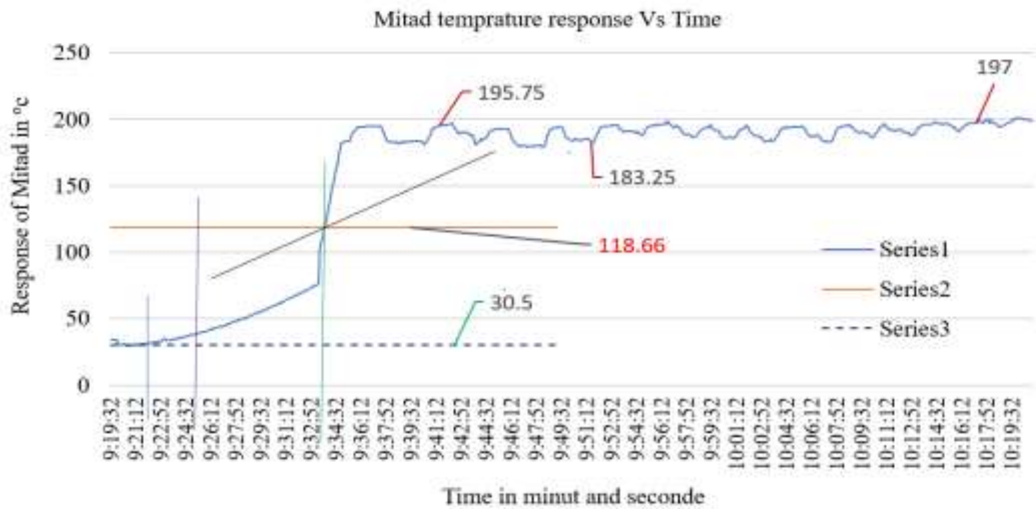


Figure 3.22. Load profile of mitad Vs. operating time experimental test value

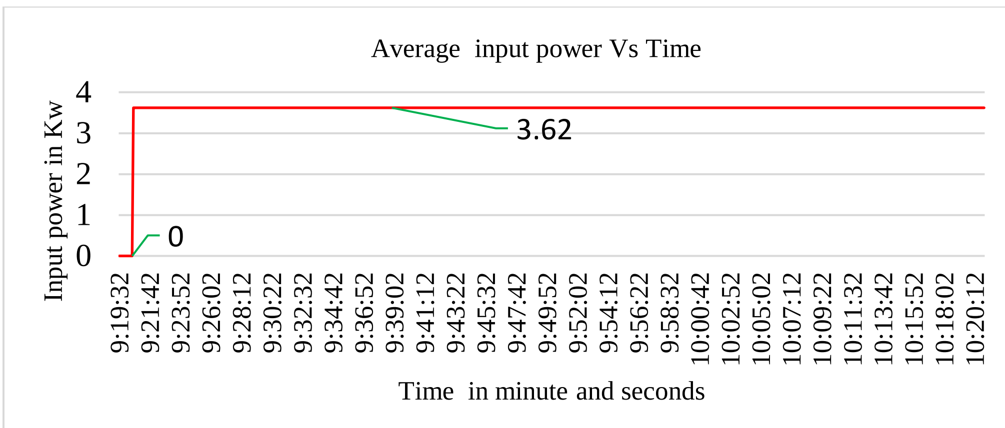


Figure 3.23. Average input power supply profile

3.5.2. Transfer Function of the plant

Based on the constant values identified time delay, steady-state gain, and time constant from the experimental data the first-order transfer function with time delay is expressed based on equation Where:

1. K_p is the steady-state gain.
2. τ_p is the time constant, it is basically how fast it takes from one steady state to the other
3. θ_p is the time dead time.

4. s is the Laplace transform variable.

$$G(S) = \frac{Ke^{-\theta S}}{\tau s+1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

$$\tau p \frac{dy(t)}{dt} = -y(t) + Kpu(t - \theta p) \ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$

A first-order linear system with dead time using a graphical method

Change in output from step response $\Delta y = 217.5 - 30 = 187.75\ o_c$

Change in input from step response $\Delta u = 3.62 - 0 = 3.62\ kw$

$$Kp = \frac{\Delta y}{\Delta u} = \frac{187.75}{3.62} = 51.9\ \frac{o_C}{\text{kw}}$$

$$0.632 \times \Delta y = 118.66\ o_c$$

$$\theta p = 365 \text{ sec}$$

$$y(t_{0.632}) = 0.632 \times \Delta y$$

$$\tau_p = t_{0.632} - \theta_p$$

$$\tau_p = 850 - 365 = 485 \text{ sec}$$

$$G(S) = \frac{51.9 \times e^{-365S}}{485s + 1}$$

Mathematical model of the system

$$dy(t) = \frac{-y(t)dt + 51.9 \times u(t-365)dt}{485} \ldots\ldots\ldots \text{(8)}$$

Dead time is where the start from, input variable starts at the starting point of the change point of the output response. While in this study the experimental values of the power supply are measured in kW. The output response was measured using a temperature data logger from the plant. Identify Time Delay, from the plot, shown in Figures 3.22 & 3.23 the time delay, θ is identified using input and output responses. The time delay is the duration of the system or Mitad temperature response to power input changes.

The experimental recording time starts from 9:19:32 up to 9:25:37 while the slop line crosses the steady state point to starting output response the value is 365 sec. The steady-state gain, K_P, is determined from the output and input ratio, considering the input is at a constant value its value is 51.9 ^{o}c / Kw.

The time constant, τ is the time it takes for the output system response to reach 63.2% of its final value. The estimation is from the time it takes for the output to reach approximately 63.2% of the change in response due to a step change in input its value at 63.2% of the output response is 485 sec. This approach assumes the system can be accurately modeled as a first-order system with a time delay. The system's dynamics are more complex, during the opening and closing of mitad as a result the noise in the data, and nonlinearities in the system can affect the model accuracy.

Matlab software Simulink modeling is used to validate, the system transfer function response. The system model is shown in Figure 3.24 below, and the simulation response of the system is depicted in the response output result temperature versus time graph.

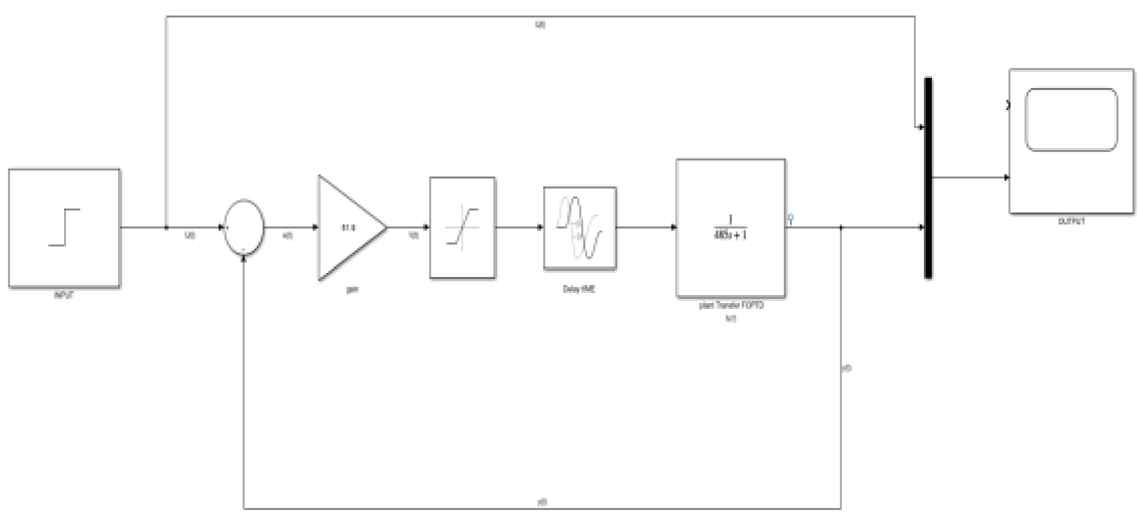


Figure 3.24. Matlab Simulink modeling of plant (system)

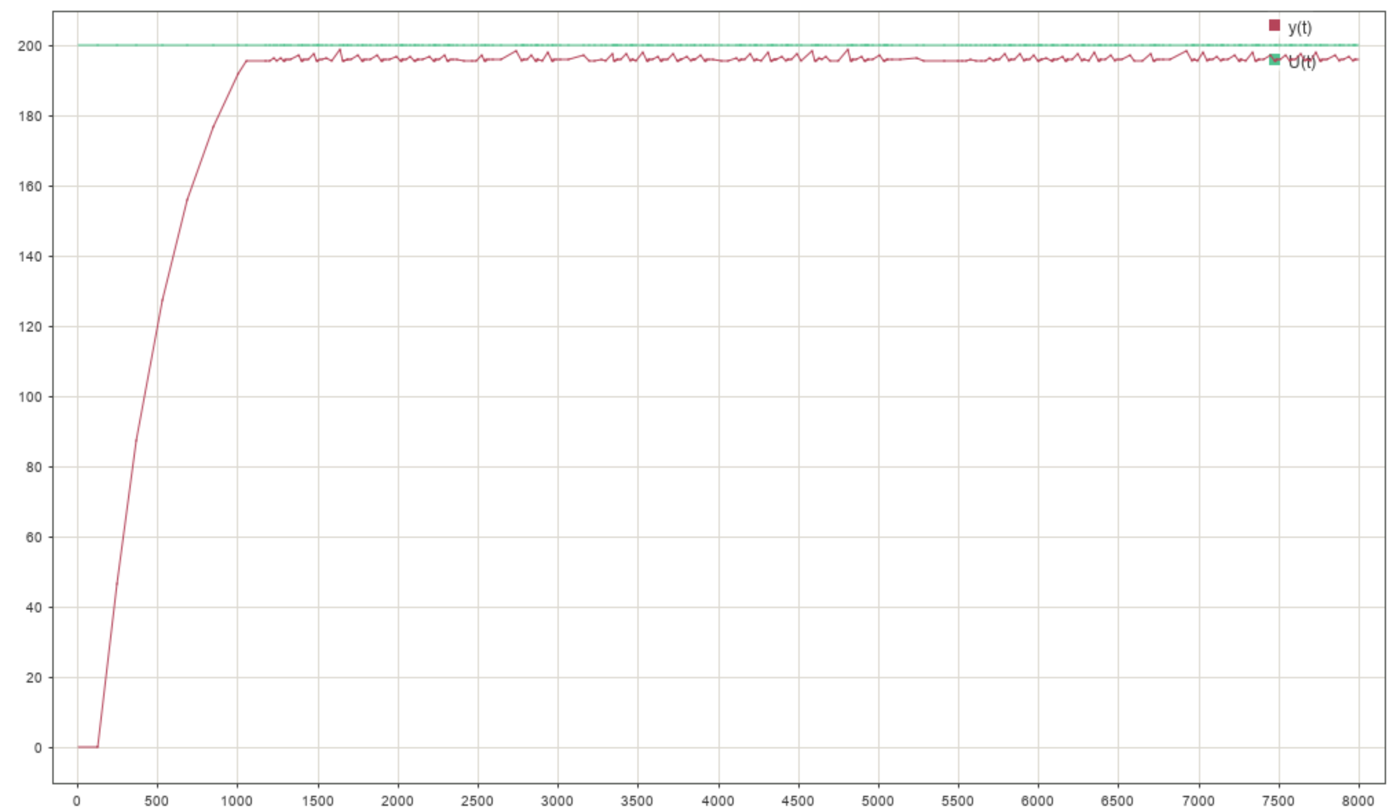


Figure 3.25. System transfer function response on Matlab Simulink simulation

The system response shown in the above figure has a similar profile to the experimental data result system response shown in Figure 3.25 which is used to determine the constants and gains of the system. That convinces the system mathematical model, it is useful for figuring out the response of a process variable at any stage of baking.

.

Chapter 4

Controller design

4.1. Design of PID Controller for electric Injera baking Mitad (EIBM)

The proposed controller comprises the following five devices microcontroller, SSR heater driver circuit, temperature sensor, and display and control algorithm. The microcontroller acts as the main brain for the device. It provides automated control of temperature reading, temperature display, and heater control. Arduino Uno microcontroller is used in this study since it provides a large library and wide hardware support.

This section explains the PID controller design of the electric Injera baking mitad. Incorporating some common tuning methods their advantage and disadvantages also selected Ziegler-Nichols tuning methods, and their parameters optimally. The first section discusses the design and steady state of the closed loop system, containing the PID controller and controlled object. To determine process dynamics of FOPTD transfer function. The process experimental data is used to determine the constant gains in section 3.4.5. Then the equivalent structural transfer function of the controller for simulation and application. Finally, discussion on optimal tuning of controller parameters for simultaneous set point tracking and disturbance rejection responses.

EIBM is a common appliance available in the household of Ethiopian. However, regulating the temperature of this device is challenging to control overheating, which affects the quality of the food being prepared. To address this issue, women take action by spraying water to cool the top surface of the mitad.

While to reduce the problems of over burning and sticking of injera on the baking mitad during the baking of injera to keep the quality of injera by controlling manually and by switching off the power supply using a breaker. The decision is performed by the person, meanwhile at the dynamic injera baking process. This study implements an automatic PID feedback temperature controller design, using a microcontroller combined with a proportional SSR power electronics actuator to regulate set point temperature.

To ensure optimal baking temperature, the average experimental test value for baking is set at 190 ^{o}c. PID control is used to control and maintain processes. It is used to control the physical output variable of EIBM surface temperature. The technique is used to achieve accurate temperature control for Ethiopian electric mitad. PID uses a simple equation, the controller uses to evaluate the controlled variable. A process variable (PV) is temperature, it measures the output on the top surface of the mitad and sends the feedback signal to the controller. The controller then compares the feedback signal to the set point (SP) and generates an error value. The value is examined with one or more of the three proportional, integral, and derivative methodologies. As a result, the controller sends the programmed signal to the actuator to execute action on the power supply system. Based on the control variable (CV) deviation from the set point to correct the error (e).

While increasing energy utilization performance, without compromising the desired qualities of injera. To increase system responsiveness, using PID parameters the controller design to applied in existing electric mitad. One of the advantages of PID is straightforward correlations between the process responses and controller parameters to be tuned of the three terms (*P*, *I*, and *D*) by the controller [60]. In practice, PID controller can be run in two modes manual or automatic [22,51]. In our study automatic mode is considered. To adjust PID parameters during operation. When there are changes in modes and parameters, it is important to avoid switching time and to implement the controller on nonstandard mitad. Based on their best-desired temperature load profile.

4.2. Implementation of PID Control

To implement a PID control, the structure of the controller selected based on the table show below referring to our plant model, which is closed-loop feedback controller. Then numerical values for the PID coefficients were estimated by tuning the transfer function of the plant with the proposed controller type.

4.3. Structure of PID Controller selection criteria

To choose the structure of a controller and tuning strategy, refer to Table 5. The table shows the tuning effects of PID controller terms, illustrating how each term can be selected to achieve specific closed-loop system requirements.

Table 6. Selection criteria for PID Controller.

	Reference Tracking Tuning		Disturbance Rejection Tuning	
	Step Reference		Constant Load Disturbance	
	Transient	Steady State	Transient	Steady State
p	Increasing *Kp* > 0 speeds up the response	Increasing *Kp* > 0 reduces but does not eliminate Steady-state offset.	Increasing *Kp* > 0 speeds up the response	Increasing *Kp* > 0 reduces but does not eliminate steady-state offset
I	Introducing integral action *Ki* > 0 gives a wide Range of Response types.	Introducing integral action *Ki* > 0 eliminates offset in the reference response	Introducing integral action *Ki* > 0 gives a wide range of Response types.	Introducing Integral action *Ki* > 0 eliminates steady-state offsets.
D	Derivative action *Kd* > 0 gives a wide range of responses and can be used to tune response Damping.	Derivative action does not affect on steady state offset	Derivative action *Kd* > 0 gives a wide range of responses and can be used to Tune response Damping.	Derivative action does not affect on Steady-state offset.

Based on the experimental temperature profile of EIBM steady, state offsets from a closed-loop output response need to be controlled. While to save energy, by reducing cases of overheating, the table indicates that D, the term is not used, and P-term used proportional gain *Kp* determine, the controller the proportional band can be determined from experimental test result process variable PV output, also to eliminate the offset I-term use. Therefore, an integral term would be chosen to present in the controller structure.

Meanwhile, the selection of PI structure, to use the integral action to eliminate constant steady state process disturbance and offset errors. In the EIBM the observed process disturbance is frequent closing and opening of Mitad cover. The temperature profile of one injera baking process is shown in section 3 of Figure 3.18.

The dynamic temperature load profile of the injera baking process requires speed up closed loop system response. The table shows that increasing the proportional gain *Kp* will have just this conclusion, proportional (*P*) action and integral (*I*) action selected, to use PI controller structure. Also, the selection of PID controller structure refers to the desired closed-loop performance. The selection process is simplified using the following PID term selection diagram. Based on this PI, structure is selected, by correlating the desired plant response and appropriate and implementable controller type for EIBM.

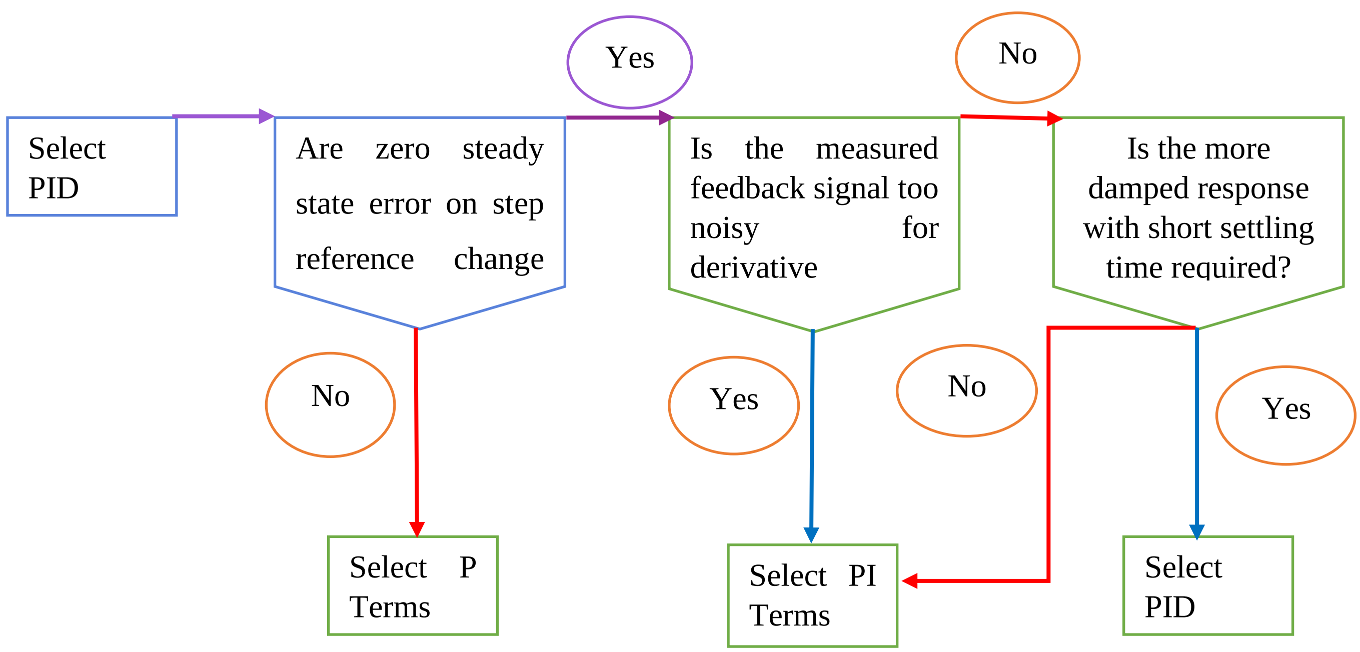


Figure 4.1. PID term selection diagram

4.4. Tuning the PID Controller

In this section setting up a PID controller is to tune or choose numerical values for the selected PI parameters [61]. PID controllers are tuned in terms of their P and I term in this study. Tuning the control gains can result in such improvements in the responses, the proportional gain *(Kp),* is typically the response and error is larger, the proportional term compensation increases [52,59]. However, an excessively large proportional gain may result in process instability and oscillation. The second term is Integral gain *(Ki)* larger integral gain implies that steady-state errors are eliminated faster after the steady state of the EIBM is reached.

Table 4 lists some common tuning methods and their advantages and disadvantages. For this study, the Ziegler- Nichols method is selected. To tune the system and controller loop for offline tuning using MATLAB Simulink [54,62]. The tuning method involves the system step change input, measuring output as a function of time, and using response to determine control parameters [52].

Table 7. Common tuning methods

Tuning Method	Advantages	Disadvantages
Manual tuning	No math requires Online method	Requires experienced personnel
Ziegler- Nichols	Proven method Online method Consistent tuning Either online or offline tuning May include an actuator and sensors analysis	Process upset Some trial and error Very aggressive tuning Involves some costs and training
Cohen-Coon	Good process models	Requires some math Offline method only Only good for first-order process

Ziegler-Nichols is a type of continuous cycling method for controller tuning. The Work under continuous oscillation with constant amplitude is based try and error procedure. The following seven steps are applied during tuning processes.

1. First allow the process to reach a steady state baking temperature range, by turning off the integral mode.

2. Then small value to proportional only controller gain *K* and place the controller in automatic mode.

3. Making a small set point change, from 190 ^{o}c up and down by adding values, the control variable moves away from the set point.

4. Increase the gain slightly, at the range of maximum and minimum voltage observed from the experiment value.

5. Then we repeat steps 3 and 4 until continuous oscillation or ultimate gain is achieved.

6. Calculated PID controller parameters using the Ziegler-Nichols tuning relation based on the table shown below.

7. Finally evaluate the Ziegler-Nichols controller settings by introducing a small set point change and observing the closed loop response.

Table 8, a. Standard PID parameter estimation

PID controller gain	P control	PI control	PID control
Kp	0.5 Kp	0.45 Kp	0.6Kp
Ki	∞	$\frac{\tau p}{1.2}$	$\frac{\tau p}{2}$
Kd	0	0	$\frac{\tau}{8}$

The value of the proportional constants of the controller is determine using the system transfer function constants again and time for the selected PI control design.

Table 8, b. Standard PID parameters value

	Value	P control	PI control
Kp		0.5 Kp	0.45 x 51.9 = 23.36
Ki			$\frac{485}{1.2} = 404.2$

Table 9, a. S shape response parameter estimation

Types of controllers	P	PI	PID control
Kp	$\frac{\tau p}{\theta p}$	$0.9\frac{\tau p}{\theta p}$	$1.2\frac{\tau p}{\theta p}$
Ti	∞	$\frac{\theta p}{0.3}$	$2\ \theta_p$
Td	0	0	$0.5\ \theta_p$

Table 9, b. S shape response parameter values

Types of controllers	PI
Kp	$0.9\frac{\tau p}{\theta p} = 0.9 \times \frac{485}{365} = 1.19$
Ti	$\frac{\theta p}{0.3} = \frac{365}{0.3} = 1216.67$
Ki	$Ki = \frac{\mathrm{Kp}}{\mathrm{Ti}} = \frac{1.19}{1216.67} = 0.00098$

4.5. PID Controller for EIBM

The desired target temperature of the EIBM is set based on the experimental test result. Measured from locally made electric mitad. The temperature profile is shown in Figure 20. The value is referred to determine the proportional controller input voltage value. To regulate process variables accordingly. The closed-loop feedback controller type uses proportional SSR to adjust the value of the AC voltage applied to the mitad to maintain the desired temperature. The control loop is shown in the figure below 28.

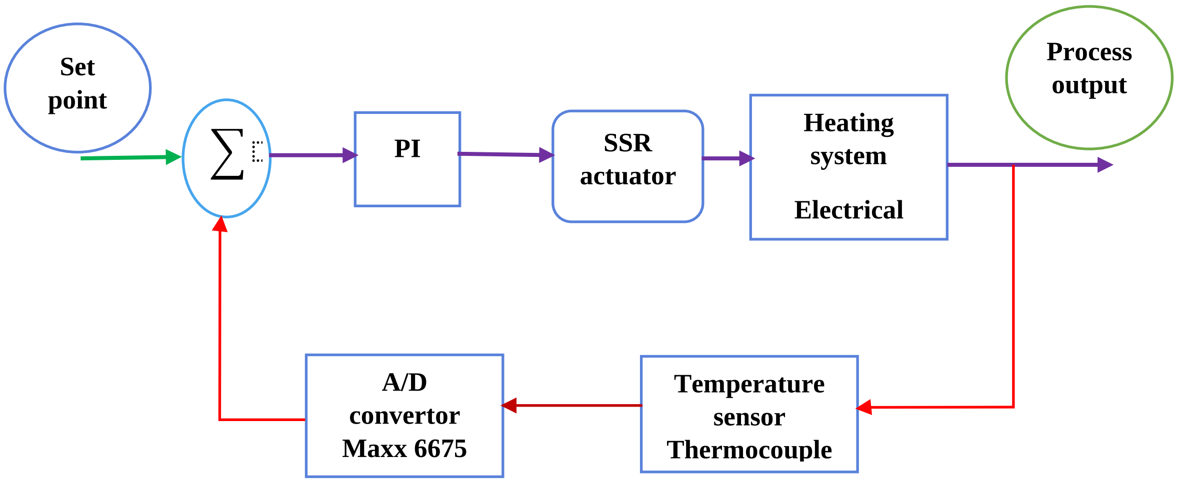


Figure 4.2. Schematic diagram of the control model with a controlled process

The temperature controller contains two components temperature control and digital to analog converter. The temperature control component compares the set point temperature with the measured temperature and generates a digital value proportional to the DC value. To trigger the applied AC voltage to load or mitad. The process variable proportional bandwidth is determined from the process output values; the value used to examine FOPTD is shown in Figure 23. Based on the considered steady-state operating temperature range of EIBM and the average experimental test result the proportional band is calculated as follows.

Direct acting loop used for controller because the process variable (PV), considered that overheat the top surface of mitad without controlling. As a result, PV is greater than the set point. Therefore, the appropriate controller action is to increase the controller output, while reducing voltage supply through the preoperational solid stat relay SSR receives a control process signal from the microcontroller to actuate regulating the voltage.

When e = PV – SP, it referred.

$$P_{out} = \mathrm{K}_p \times e \dots\dots\dots\dots\dots\dots (9)$$

Where;

Pout: Proportional portion of controller output

Kp: Proportional gain

e: Error signal, *e* = Set point – process variable

The rule of thumb indicates that a smaller proportional band (or large gain) results in a faster response to a given input error.

$$P_{band} = 217.75 - 179.75 = 40\ o_C$$

The average experimental temperature value of the process variable response is 190 ^{o}c so based on the process gain and the ambient temperature of the kitchen measured during the baking process, the value is 30.5 ^{o}c.

The experimental measured temperature of mitad is between 217.75°c and 179.75 °c, the system response is proportional. So that the voltage should be controlled proportional to the error. When the temperature is below 179.75 °c the voltage is provided 100%. When it is above 217.75 °c, the voltage is provided 0% or off state. The proportional band (or reciprocal of gain) in this case is 40°c. The full controller range is determined by considering the initial room temperature is 30.5°c. Therefore, the proportional band in percentage is determined.

$$T_{max} - T_a$$

$$P_{band=}\ \frac{\Delta T_s}{T_{max} - T_a}\ x100$$

$$217.75\ °\text{c} - 30.5\ °\text{c} = 187.25°\text{c}$$

$$P_{band=} \frac{40°\text{c}}{187.25°\text{c}} \times 100 = 21.3\%$$

However, the preoperational control can't compensate very small error offset values, so that integral control system should be applied to attempt and correct small offset errors.

Feedback Controllers

The PID controller is used to comprise, a PI-type feedback controller $G_C(s)$ have the following mathematical model.

$$\text{Gc(S)} = K_p \left[1 + \frac{1}{T_i\,\text{s}}\right] \ldots \ldots \ldots \ldots \ldots \ldots . . (10)$$

$$\text{Gc(S)} = 23.36[1 + \frac{1}{404.2\text{s}}]$$

$$U(t) = K_p \ e(t) + \frac{1}{T_i}\int_0^t e(t)dt \ldots\ldots\ldots\ldots\ldots(11)$$

$$U(t) = 23.36\, e(t) + \frac{1}{404.2}\int_0^t e(t)dt$$

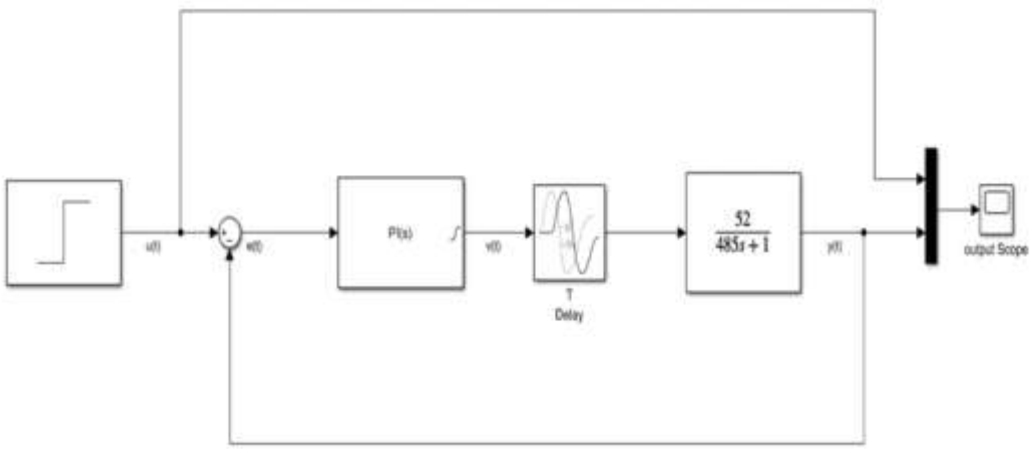


Figure 4.3. Simulink model of PI controller with process FOPTD

Table 10. Automatic Ziegler- Nichols tuning results

Controller parameters	Tuned 1	Tuned 2	Tuned 3	Tuned 4	Tuned 5
Response time in the second	1248	1528	976.5	975	1172
p	0.015318	0.01102	0.003959	0.0046	0
I	3.0347×10^{-5}	2.6027×10^{-5}	3.688×10^{-5}	3.83×10^{-5}	3.282×10^{-5}
Performance and robustness	0.576	0.594	0.693	0.683	0.531
Rise time (Seconds)	544	510	392	335	497
Settling time (Seconds)	2.01×10^3	2.22×10^3	1.43×10^3	2.31×10^3	2.66×10^3
Overshoot	9.2%	6.24%	5.18%	6.08%	14.8%
Peak	1.09	1.07	1.05	1.06	1.15

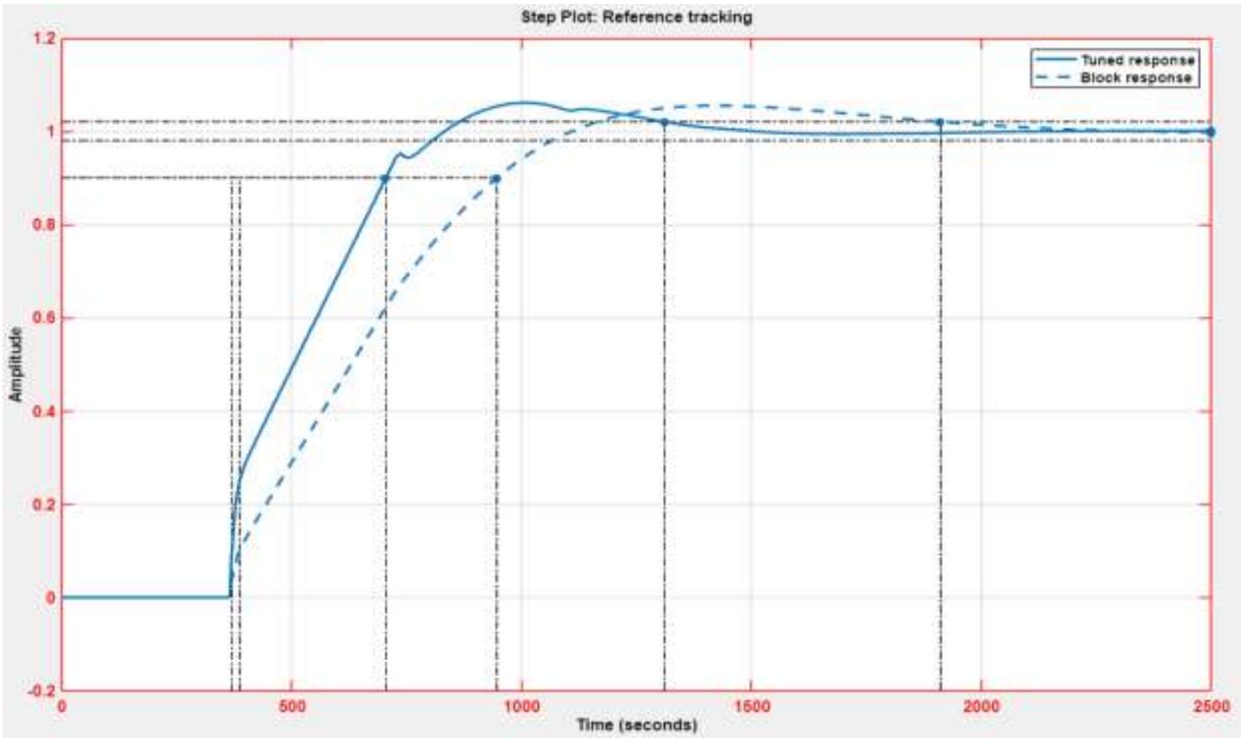


Figure 4.4. Set point tracking for 3rd tuning

After a few tunings of the Simulink model with a transfer function of the system and PI constants the figure shown below the tuning results provide less settling time, low overshot, and relatively low rising time, at 69.3%, Performance and robustness and less response time show in Table 10 the third tuning P and I constants used to develop the controller. The other tuned response effect versus time, graphs are included in the appendix part of the document.

After determining the constants of the proposed controller, the controller is built and tested in the actual plant or EIBM. The following two figures show the experimental setup used to perform the controller test.

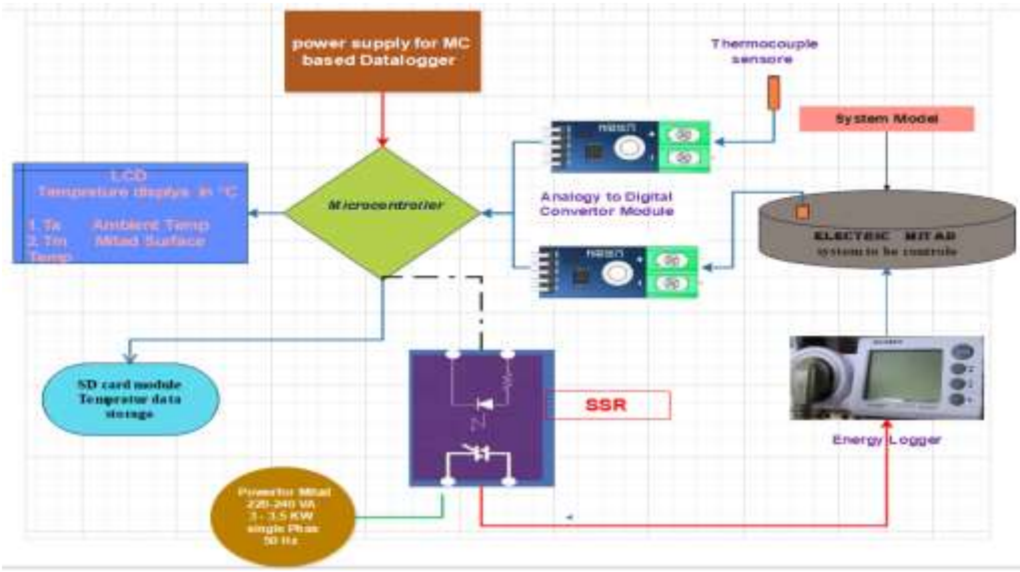


Figure 4.5. Schematic diagram of 2nd Experimental setup of temperature controller

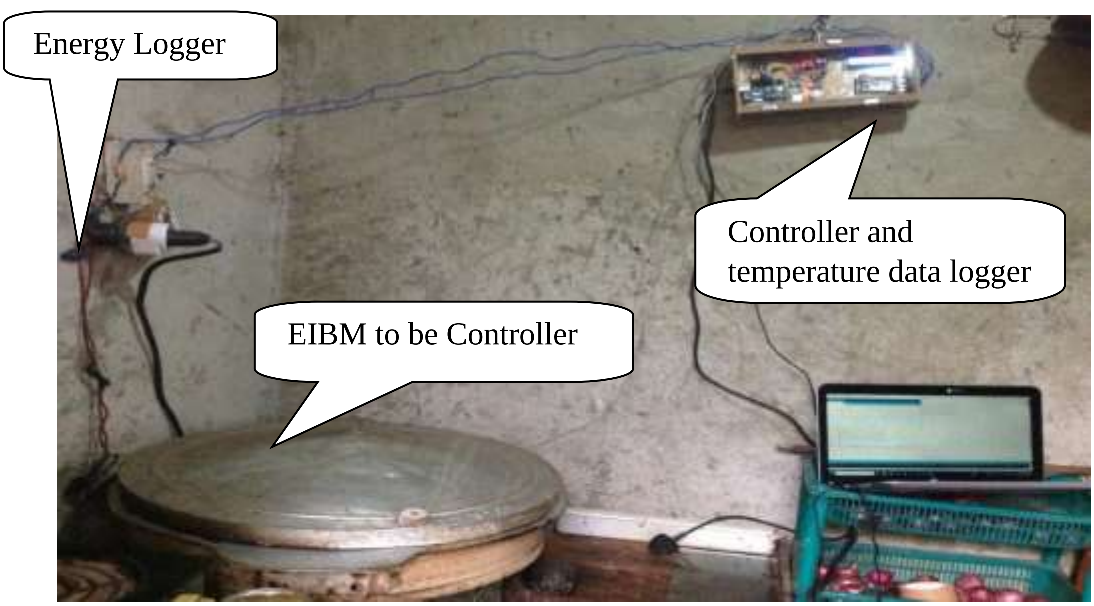


Figure 4.6. Full Experimental setup of a temperature controller and data loggers

As shown in Figures 4.5 and 4.6 schematic diagrams of the experimental setup and the actual setup the temperature and the energy consumption were measured by applying the controller.

Chapter 5

Result and discussion

.

The EIBM with feedback controller system regulates the set point or desired temperature at different ranges as well by rejecting disturbance. The temperature variation of controlled and uncontrolled EIBM and its comparison is depicted in Figure 5.2 below. Table 4 shows the operating hours, the number of injera baked, and the total energy consumption for each test reported before the controller is applied to the plant.

As a result of the controller, the bandwidth variation of temperature reduces, and it approaches the set point temperature. This is due to control of input power, which is supplied to EIBM, proportionally by tracking output set point temperature. The result indicates that the temperature variation of controlled EIBM is measured at 4.5 ^{O}C and 8.75 ^{O}C variation from the set point. The comparison is shown in Figure 5.2 legend series 4 and 5 respectively and their bandwidth is 2.78 % and 5.34 % respectively tabulated in Table 11.

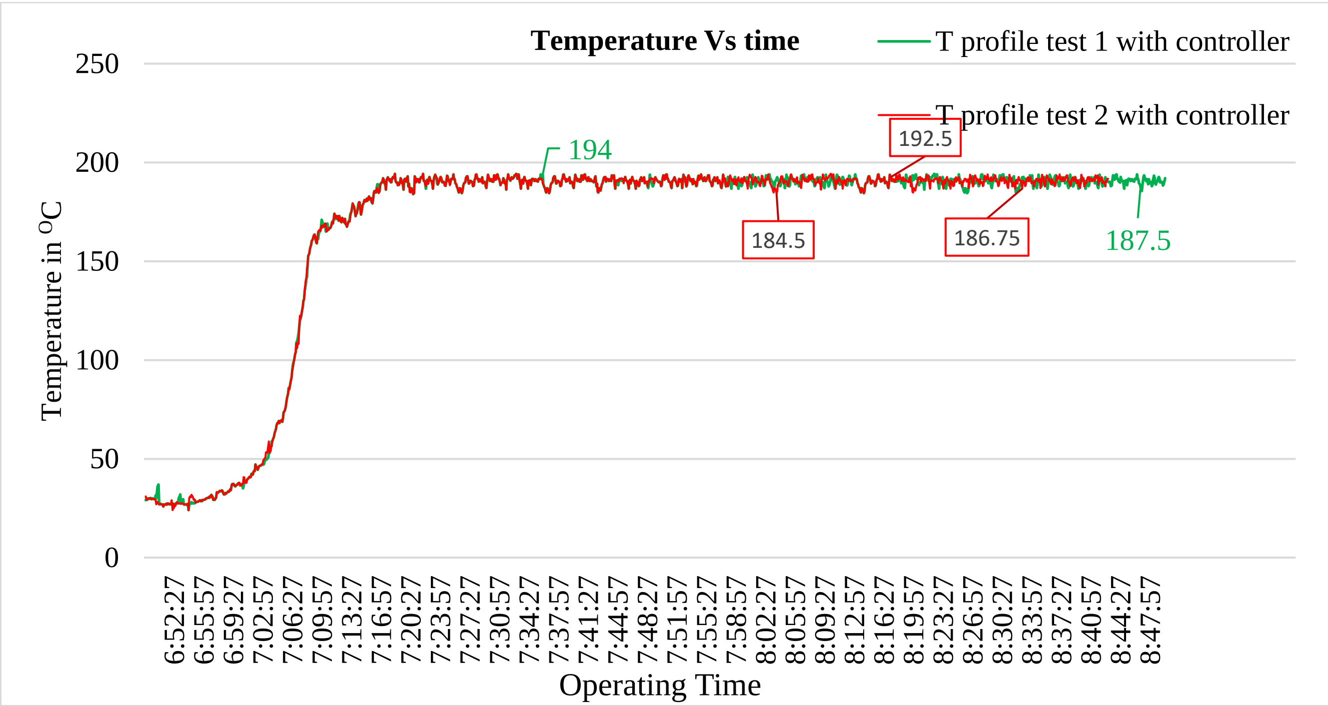


Figure 5.1. Temperature profile of Mitad with a controlled condition

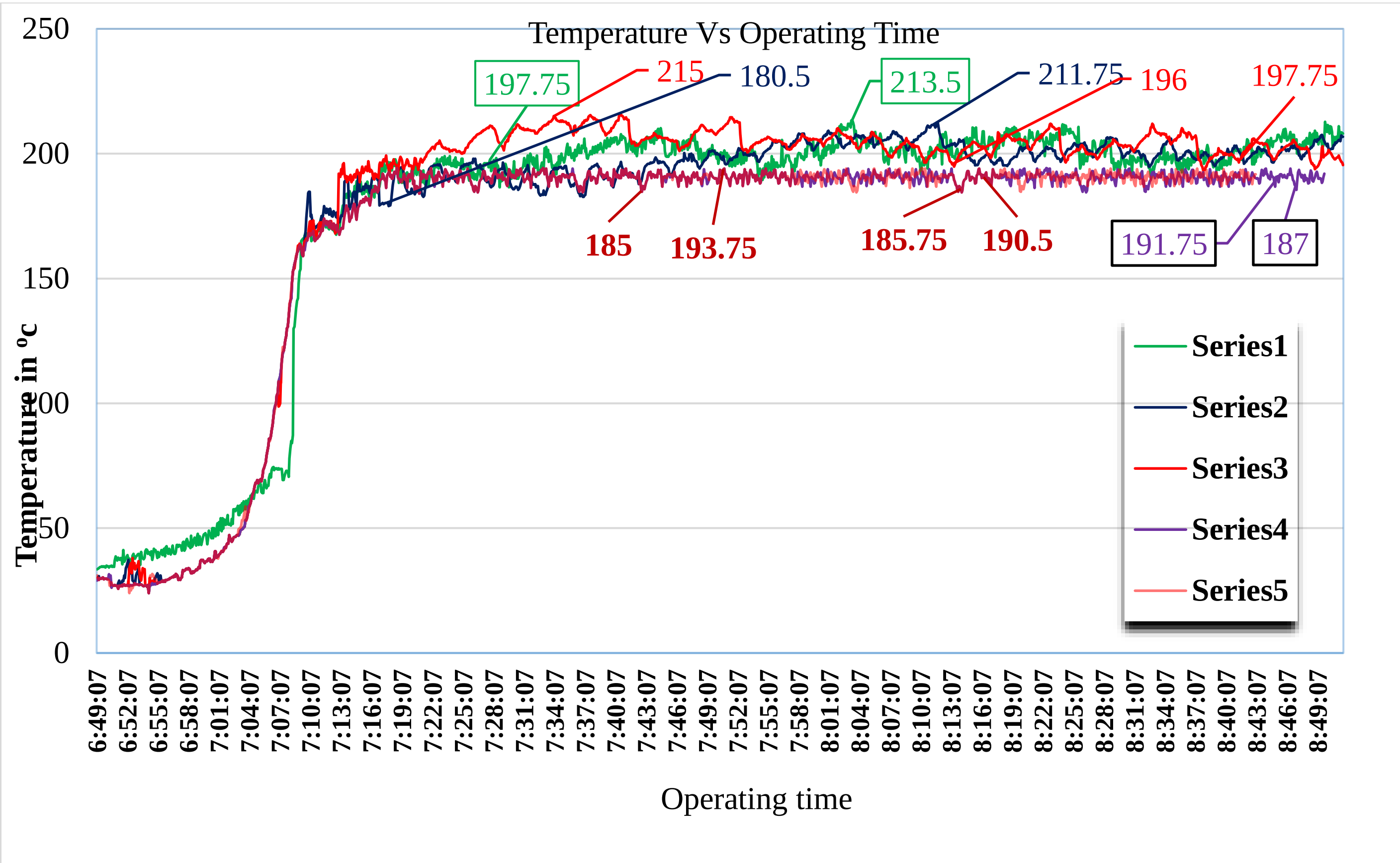


Figure 5.2. Temperature profile of Mitad with controlled and uncontrolled condition

The surface temperature of the Mitad shown in Figure 5.1 represents the recommended operating temperature range for baking injera. This temperature fluctuates from the average setpoint within the negative and positive ranges. When the developed controller is applied, the operating temperature is tracked.

Table 11 Surface temperature gradient EIBM process with controller

Test	Temperature Maximum in OC	Temperature Minimum in ^{O}C	Chang Temperature in ^{O}C	Temperature Ambient in ^{O}C	Band width in %
1	193.75	185	8.75	30	5.34 %
2	191.5	187	4.5	30	2.78 %

Table 12. Experimental tests result in total energy consumption and operating time of controlled EIBM.

Test	Test date	Total baking time	Baking starts after	Number of baked injera	Energy consumption in Kwh
1	June 17	2hr and 01 minute	18minute	42	**6.752**
2	June 22	1 hr and 54 minutes	17 minute	37	**6.24**

Table 13. Experimental tests result in energy consumption and baking time per injera of controlled EIBM

Test	Test date	Total baking time in minutes	Number of baked injera	Average injera baking time in minutes and second	Energy consumption in Wh	Energy consumption Per injera in Wh
1	June 17	121	42	2:53	6,752	160.8
2	June 22	114	37	3:05	6,240	168.65
Average test result				**2:59**		**164.73**

The average energy consumption of controlled and uncontrolled EIBM per injera is 164.73Wh and 196.33 Wh respectively. As a result, 31.6 Wh, or 16.1% of energy per injera is reduced. while using a controller. The average baking time of controlled and uncontrolled EIBM per injera is 179 seconds and 218 seconds per injera respectively. As a resulte 39 second, or 17.9 % per injera reduced.

The maximum theoretical energy savings occur at the minimum baking temperature. Doubling the energy savings is possible without considering the baking time, although it will take a longer time to bake one injera. However, this requires experimental testing and analysis by changing the set point baking temperatures at different values. The theoretical maximum energy savings are estimated at 32.2% per injera.

5.2. Conclusion

In this study, a microcontroller-based automatic temperature control system for IEBM was developed and tested. The proposed controller aims to regulate the surface temperature of the mitad to maintain the desired baking temperature. The system successfully maintained a specific temperature range, carefully controlled by a microcontroller to keep the average set baking temperature. Power consumption and baking time decreased, with the percentage values tabulated in Table 13. Consequently, the feedback type automatic on-off PI control system applied and tested on EIBM, reduced energy consumption per injera by 16.1% and average baking time by 17.9%.

The PID controller is a popular choice in control systems due to its remarkable effectiveness and simplicity of implementation. In this paper, Ziegler-Nichols tuned PID controllers for the EIBM system were investigated. This tuning method is used to determine the parameter settings for the PI controller. Experimental test results of controlled and uncontrolled Mitad showed that the top surface temperature of uncontrolled mitad has a higher value than the required average setpoint. As a result, the surplus heat energy is lost. So, the temperature controller for the EIBM baking process is crucial to reduce the national energy demand used for baking injera. Also, it reduces the electricity costs for users. Additionally, using a controller will save energy. Also, it will help to implement efficiency standardization of the existing device without replacing the currently used electric Mitad. From the minimum of 331.8 GWh of energy loss predicted in section 1, approximately 53.46 GWh of energy can be saved annually

Recommendation

The findings suggest that process control can lead to energy savings. Additional research on electric injera baking process control is needed to save energy. Remarkably, maintaining a minimum baking setpoint temperature will increase the energy savings by half. We strongly recommend that interested researchers focus on maintaining a minimum baking temperature.

General recommendations:

- Policies should mandate the application of controllers on existing electric Mitads to support EIBM standardization.
- Ethiopian Electric Utility should enforce the adoption of such controllers on the existing EIBMs.

Reference

[1] K.D. Adem, D.A. Ambie, A review of injera baking technologies in Ethiopia: Challenges and gaps, Energy Sustain. Dev., Vol. No. 41, (Year 2017) Page 69–80.

[2] A.H. Tesfay, M.B. Kahsay, O.J. Nydal, Solar powered heat storage for Injera baking in Ethiopia, Energy Procedia, Vol. No. 57, (Year 2014) Page 1603–1612.

[3] E. Sánchez-Jacob, A. González-García, J. Mazorra, P. Ciller, J. Lumbreras, J.I. Pérez-Arriaga, Joint optimal planning of electricity and modern energy cooking services access in nyagatare, Energies, Vol. No. 14, (Year 2021) Page 1–24.

[4] N. Kebede, D. Tolossa, T. Tefera, Adoption of improved cook stoves by households in informal settlements of Woreda 12, Yeka subcity, Addis Ababa, Energy. Sustain. Soc., Vol. No. 12, (Year 2022) Page 1–15.

[5] R. Jones, J.C. Diehl, L. Simons, M. Verwaal, The development of an energy efficient electric Mitad for baking injeras in Ethiopia, Proc. 25th Conf. Domest. Use Energy, DUE 2017, (Year 2017) Page 75–82.

[6] K. Mitad, improving energy consumption and durability of the clay bakeware (MITAD) Alula Gebresas Asmamaw Tegegne Hadush Berhe Abdelkadir Kedir 2 . materials and methods 2 . 1 . Study Area Selection and Data Collection Keywords, (n.d.) Page 7–14.

[7] K.W. Liyew, N.G. Habtu, Y. Louvet, D.D. Guta, U. Jordan, Technical design, costs, and greenhouse gas emissions of solar Injera baking stoves, Renew. Sustain. Energy Rev., Vol. No. 149, (Year 2021) Page 111392.

[8] M.H. Hailu, M.B. Kahsay, A.H. Tesfay, O.I. Dawud, Energy consumption performance analysis of electrical mitad at Mekelle City, Momona Ethiop. J. Sci., Vol. No. 9, (Year 2017) Page 43.

[9] F.T. Teferi, K.P. Kolhe, Design and Analytical Study For Influence Of Thermal Insulation On Ethiopian Electric Injera Baking Pan (MITAD), J. Eng. Sci. Technol., Vol. No. 16, (Year 2021) Page 5071–5086.

[10] G. Moges, Electric Injera Mitad Energy Efficiency Standards & Labeling, challenges and prospects, Vienna Energy Forum 2017, (Year 2017) Page 35.

[11] S.M. Negash, I.M.B. Omiogbemi, I.M. Dagwa, Development of a partially automated electric injera baking stove with improved efficiency and production rate, AIP Conf. Proc., Vol. No. 2341, (Year 2021).

[12] F.F. M., Design and Development of Microcontroller Based Electromagnetic Induction Injera Mitad Prototype, Int. J. Recent Technol. Eng., Vol. No. 9, (Year 2020) Page 322–326.

[13] Á. Herrero, B. Baruque, F. Klett, A. Abraham, V. Snášel, A.C.P.L.F. De Carvalho, P.G. Bringas, I. Zelinka, H. Quintián, E. Corchado, Preface, Adv. Intell. Syst. Comput., Vol.

No. 239, (Year 2014) Page v–vi.

[14] D.T. Nega, B. Mulugeta, S.W. Demissie, Improved biogas ‘Injera’ bakery stove design, assemble and its baking pan floor temperature distribution test, Energy Sustain. Dev., Vol. No. 61, (Year 2021) Page 65–73.

[15] A. Kegne, Investigating performance improvement of eletric injera baking mitad using steel powder as additive material, MSc thesis, (Year 2021) Page 110. https://ir.bdu.edu.et/handle/123456789/13382.

[16] I. Journal, IRJET- Design and development of Electromagnetic Induction Injera Mitad, (n.d.).

[17] A.T. TAFERE, Experimental Investigation on Performance Characteristics and Efficiency of Electric Injera Baking Pans („Mitad‟), A Thesis Submitt. To Sch. Grad. Stud. Addis Ababa Univ. Partial Fulfillment Requir. Degree Masters Sci. Energy Technol., (Year 2011).

[18] Z. Gebreegziabher, A. Mekonnen, M. Kassie, G. Köhlin, Urban energy transition and technology adoption: The case of Tigrai, northern Ethiopia, Energy Econ., Vol. No. 34, (Year 2012) Page 410–418.

[19] M.N. Feyisa, Determinants of Household Adoption of Electric Injera Mitad in Urban Ethiopia : A Case Study of Woliso Town, Vol. No. 9, (Year 2019) Page 216–221.

[20] Improvement of Existing Electric Mitad By Mechanical and Thermal Design Alteration for Heat Loss Reduction, (Year 2021).

[21] R. Aisuwarya, Y. Vidiana, Smart Rice Cooker with PID Method to Warm Food using Android Application, Mecn. 2020 - Int. Conf. Mech. Electron. Comput. Ind. Technol., (Year 2020) Page 261–266.

[22] M.B.N. Shah, N. Zailan, A.F.Z. Abidin, M.F. Halim, K.A. Annuar, A.H. Azahar, M.H. Harun, M.F. Yaakub, PID-based temperature control device for electric kettle, Int. J. Electr. Comput. Eng., Vol. No. 9, (Year 2019) Page 1683–1693.

[23] H.B. Lin, A kind of intelligent temperature controller use PID algorithm to realize, 2011 Int. Conf. Electr. Control Eng. ICECE 2011 - Proc., (Year 2011) Page 2838–2840.

[24] A.K. Ho, Fundamental of PID Control, PDH Cent., Vol. No. 331, (Year 2014) Page 1–19.

[25] R. Godina, E.M.G. Rodrigues, E. Pouresmaeil, J.C.O. Matias, J.P.S. Catalão, Model Predictive Control home energy management and optimization strategy with demand response, Appl. Sci., Vol. No. 8, (Year 2018).

[26] A. Herreros, E. Baeyens, J.R. Perán, Design of PID-type controllers using multiobjective genetic algorithms, ISA Trans., Vol. No. 41, (Year 2002) Page 457–472.

[27] J. Zhang, H. Li, K. Ma, L. Xue, B. Han, Y. Dong, Y. Tan, C. Gu, Design of PID temperature control system based on STM32, IOP Conf. Ser. Mater. Sci. Eng., Vol. No. 322, (Year 2018).

[28] R.S. Sabale, P.J. V Bute, Microcontroller based Temperature Controller System, Int. Res. J. Eng. Technol., (Year 2020) Page 912–914.

[29] A. Marisiensis, S. Technologica, M. Dulău, on-Off Algorithm Combined With Pid Algorithm, Vol. No. 16, (Year 2019) Page 5–9.

[30] M. Prist, E. Pallotta, P. Cicconi, A.C. Russo, A. Monteriu, M. Germani, S. Longhi, An automatic temperature control for induction cooktops to reduce energy consumption, 2018 IEEE Int. Conf. Consum. Electron. ICCE 2018, Vol. No. 2018-Janua, (Year 2018) Page 1–6.

[31] A.L. Amoo, H.A. Guda, H.A. Sambo, T.L.G. Soh, Design and implementation of a room temperature control system: Microcontroller-based, 2014 IEEE Student Conf. Res. Dev. SCOReD 2014, (Year 2014).

[32] P.S. Iskrenović, G.B. Sretenović, I.B. Krstić, B.M. Obradović, M.M. Kuraica, Thermostat with Peltier element and microcontroller as a driver, Meas. J. Int. Meas. Confed., Vol. No. 137, (Year 2019) Page 470–476.

[33] M.M. Gani, M.S. Islam, M.A. Ullah, Optimal PID tuning for controlling the temperature of electric furnace by genetic algorithm, SN Appl. Sci., Vol. No. 1, (Year 2019) Page 1–8.

[34] N. Hambali, A.A.R. Ang, A.A. Ishak, Z. Janin, Various PID controller tuning for air temperature oven system, 2014 IEEE Int. Conf. Smart Instrumentation, Meas. Appl. ICSIMA 2014, (Year 2015) Page 26–27.

[35] J.A. Herrera-Morales, H. Carbajal-Morán, Á. Almidón-Elescano, Solar Dryer with Electronic PID Controller for Dry Potato Production, Ecol. Eng. Environ. Technol., Vol. No. 23, (Year 2022) Page 223–229.

[36] C. Engineering, Embedded Design of Temperature Controller Using Pic 16f876a For Industries And Labortories, (Year 2013) Page 2414–2422.

[37] M. Jenko, Design of precise and long-term accurate temperature regulation using features of a low- Zasnova precizne in dolgotrajno točne temperaturne regulacije z uporabo lastnosti mikrokontrolerja za majhno porabo moči, Vol. No. 40, (Year 2010).

[38] N. Patience, I.A. Ejeh, Nabiryo and Itodo 53 Design and Implementation of Base Station Temperature Monitoring System Using Raspberry Pi Design and Implementation of Base Station Temperature Monitoring System Using Raspberry Pi, (Year 2022).

[39] P. Sihombing, T.P. Astuti, Herriyance, D. Sitompul, Microcontroller based automatic temperature control for oyster mushroom plants, J. Phys. Conf. Ser., Vol. No. 978, (Year 2018).

[40] O.. Shoewu, O.. Ayangbekun, L.. Akinyemi, C. Agbai, Development and Implementation of Fuzzy-Like Temperature Controller for a Rice Cooker, Vol. No. 11, (Year 2021) Page 42–52.

[41] Y.J. Chen, Design of temperature control system based on FPGA and fuzzy-PID control algorithm, Appl. Mech. Mater., Vol. No. 599–601, (Year 2014) Page 1124–1127.

[42] H.K.M. Reddy, MATLAB / SIMULINK Based Oven Temperature Control through Simulation Studies using PIDC, Vol. No. 5, (Year 2013) Page 81–84.

[43] M. Elnour, W.I.M. Taha, PID and fuzzy logic in temperature control system, Proc. - 2013 Int. Conf. Comput. Electr. Electron. Eng. 'Research Makes a Differ. ICCEEE 2013, (Year 2013) Page 172–177.

[44] V.S. Narwane, B.E. Narkhede, V. V. Bhosale, P. Jain, Comparative analysis of pid and fuzzy logic controller: A case of furnace temperature control, J. Curr. Sci. Technol., Vol. No. 10, (Year 2020) Page 109–120.

[45] M. Stephenson, Northumbria Research Link (www.northumbria.ac.uk/nrl), Acad. Manag., Vol. No. 51, (Year 2021) Page 1–51.

[46] J. Park, R.A. Martin, J.D. Kelly, J.D. Hedengren, Benchmark temperature microcontroller for process dynamics and control, Comput. Chem. Eng., Vol. No. 135, (Year 2020) Page 106736.

[47] M. Khairudin, B. Ibrahim, F. Arifin, B. Rohjai, A.P. Duta, F. Nurhidayah, I.G. Mahendra, Temperature control based on fuzzy logic using atmega 2560 microcontroller, J. Phys. Conf. Ser., Vol. No. 1737, (Year 2021).

[48] A.L. Osasere, Enhanced Safety in Cooking: Microcontroller-based Single-Burner Electric Cooker with Buzzer, … -Based Single-Burner Electr. Cooker with Buzzer, (Year 2019). http://ijrp.org/paper-detail/859.

[49] V.B. Kumar, K.S. Rao, G. Charan, Y. V. Pavan Kumar, Industrial heating furnace temperature control system design through fuzzy-pidcontroller, 2021 IEEE Int. IOT, Electron. Mechatronics Conf. IEMTRONICS 2021 - Proc., Vol. No. 1, (Year 2021).

[50] A.A. Jamil, W.F. Tu, S.W. Ali, Y. Terriche, J.M. Guerrero, Fractional-Order PID Controllers for Temperature Control: A Review, Energies, Vol. No. 15, (Year 2022).

[51] G.L. Deshmukh, C.B. Kadu, Design of two degree of freedom PID controller for temperature control system, Int. Conf. Autom. Control Dyn. Optim. Tech. ICACDOT 2016, (Year 2017) Page 586–589.

[52] L. dos Santos Coelho, Tuning of PID controller for an automatic regulator voltage system using chaotic optimization approach, Chaos, Solitons and Fractals, Vol. No. 39, (Year 2009) Page 1504–1514.

[53] H. Bastida, C.E. Ugalde-Loo, M. Abeysekera, M. Qadrdan, J. Wu, Thermal dynamic modelling and temperature controller design for a house, Energy Procedia, Vol. No. 158, (Year 2019) Page 2800–2805.

[54] E.D. Bolat, K. Erkan, S. Postalcioğlu, Implementation of microcontroller based temperature control using autotuning PID methods, Proc. 2nd Indian Int. Conf. Artif. Intell. IICAI 2005, (Year 2005) Page 153–164.

[55] J. Bhor, S. Pawar, S. Das, Design and Development of Temperature Control Loop of Hair Dryer Using Arduino, 2020 Int. Conf. Ind. 4.0 Technol. I4Tech 2020, (Year 2020) Page 61–64.

[56] V.G. Ryckaert, J.E. Claes, J.F. Van Impe, Model-based temperature control in ovens, J. Food Eng., Vol. No. 39, (Year 1999) Page 47–58.

[57] D. Ibrahim, Microcontroller Based Applied Digital Control, Year 2006 .

[58] A. Gambier, MPC and PID control based on multi-objective optimization, Proc. Am. Control Conf., (Year 2008) Page 4727–4732.

[59] S.Z. Zhao, M.W. Iruthayarajan, S. Baskar, P.N. Suganthan, Multi-objective robust PID controller tuning using two lbests multi-objective particle swarm optimization, Inf. Sci. (Ny)., Vol. No. 181, (Year 2011) Page 3323–3335.

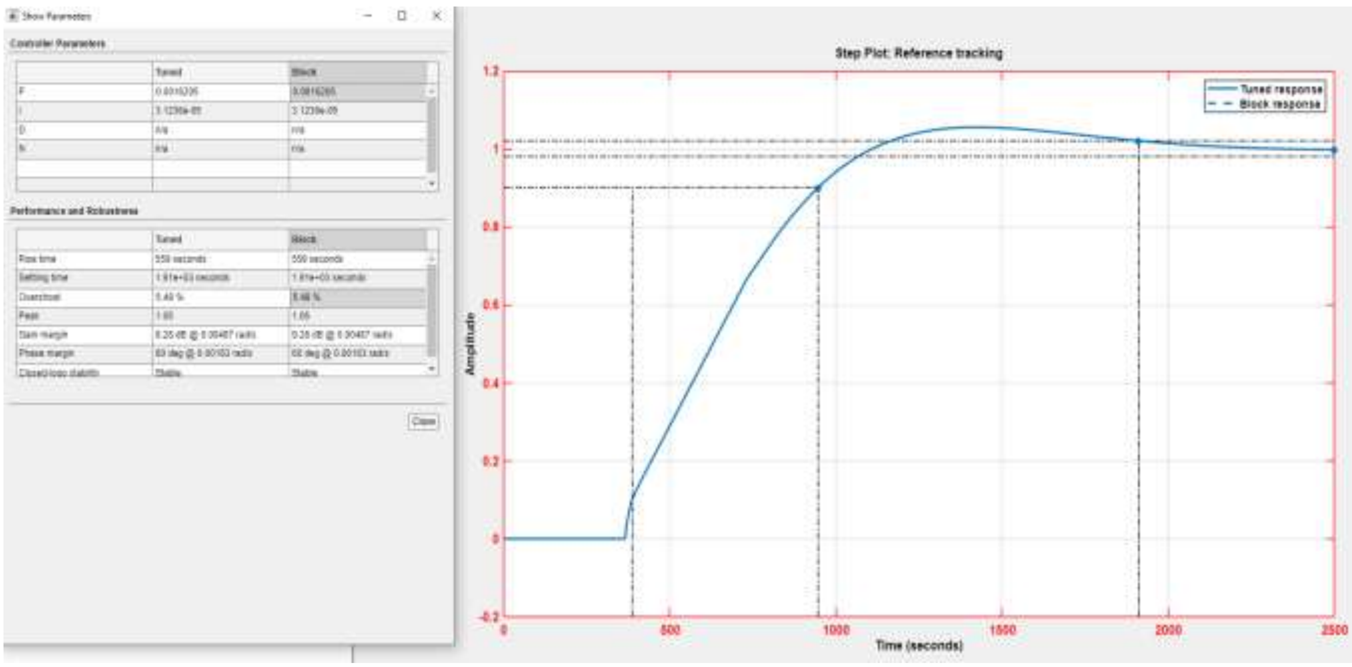
[60] G. Chen, H. Li, R. Chen, Intelligent Rice Cooker Control System Design, Vol. No. 2, (Year 2020) Page 63–71.

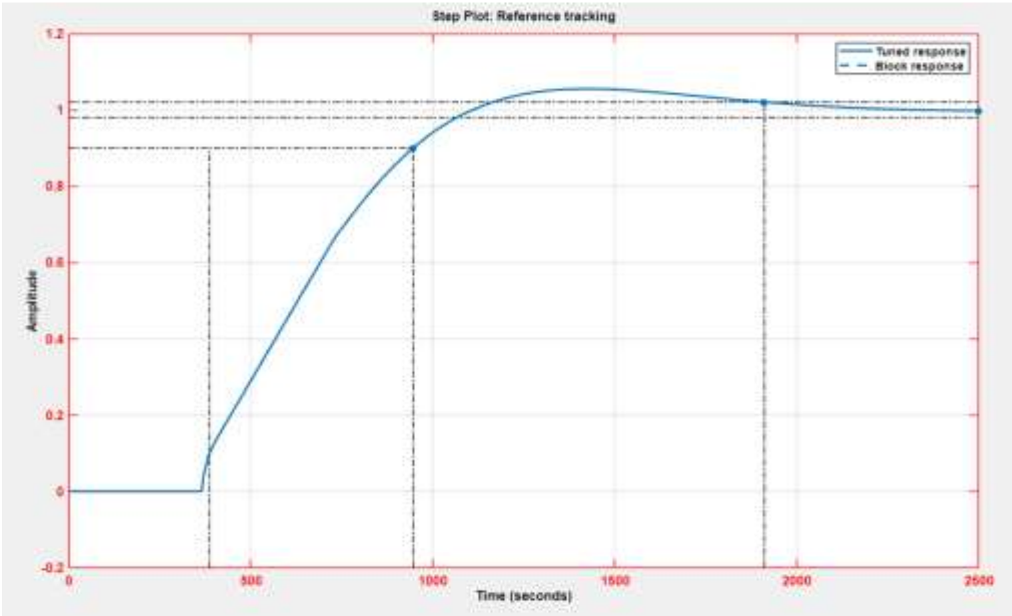
[61] N. Cervantes-Escorcia, O.J. Santos-Sánchez, L. Rodríguez-Guerrero, H. Romero-Trejo, A. González-Facundo, Optimal PI and PID Temperature Controls for a Dehydration Process, Arab. J. Sci. Eng., Vol. No. 44, (Year 2019) Page 2519–2534.

[62] G. Jin, Y. Son, Design of a Nonlinear PID Controller and Tuning Rules for First-Order Plus Time Delay Models, Vol. No. 28, (Year 2019) Page 157–166.

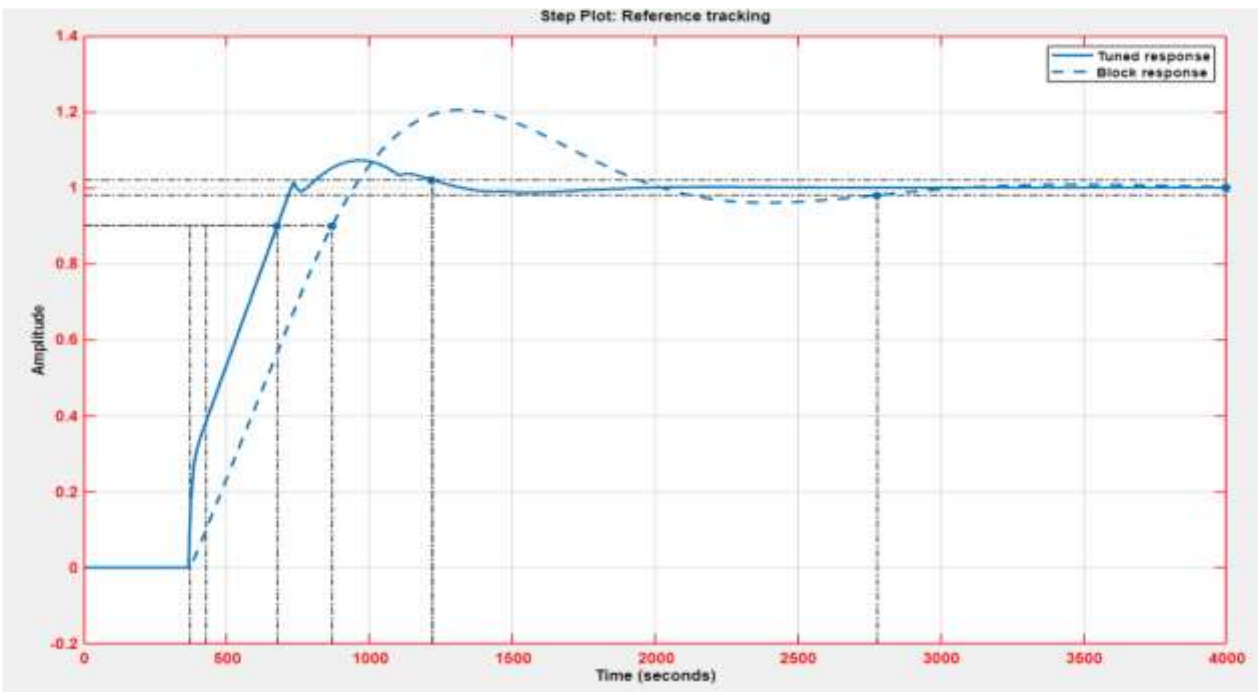
Appendix

Automatic tuning result of PI controller at different Performance, robustness, and rising time simulation result.

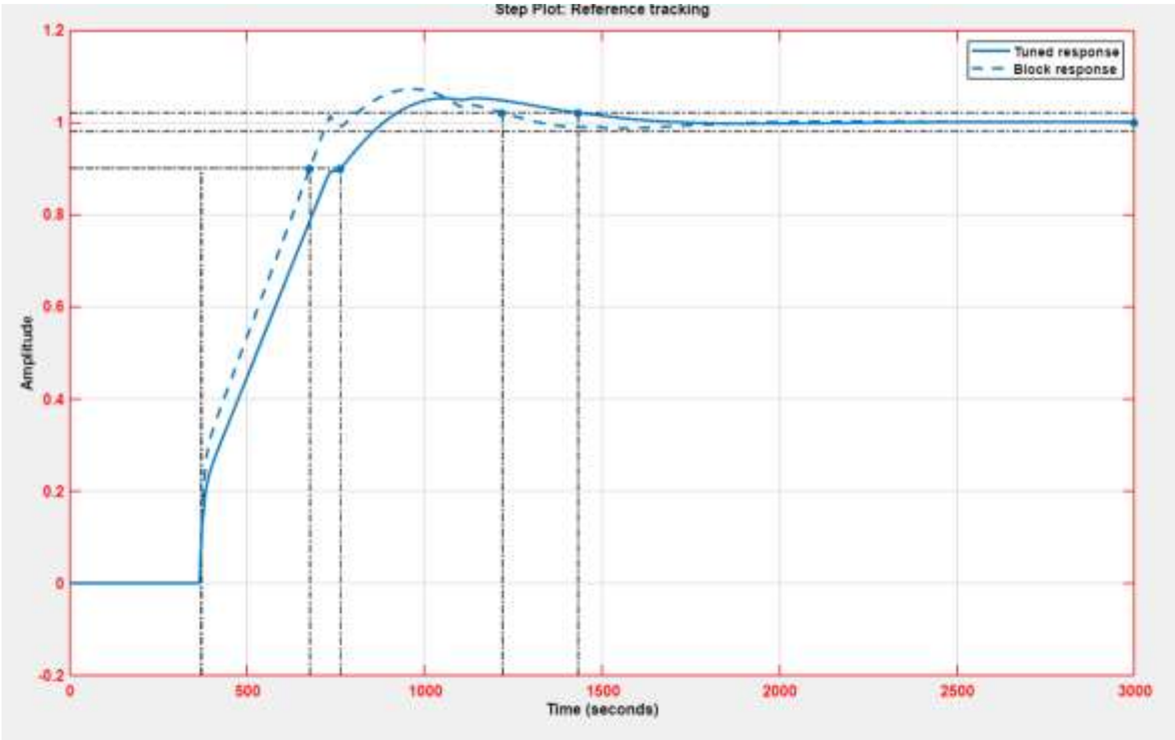




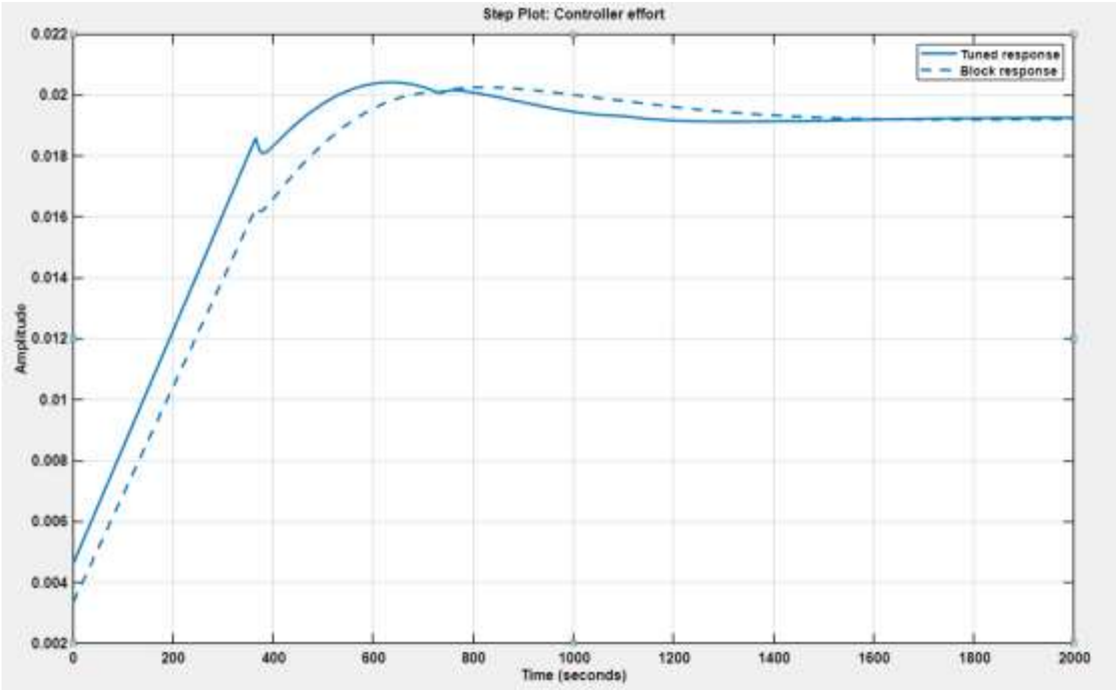
Set point tracking of 1 st tuning



Set point tracking of 2nd tuning



Set point tracking of 4^{th} tuning



Controller effect tracking for 4^{th} tuning

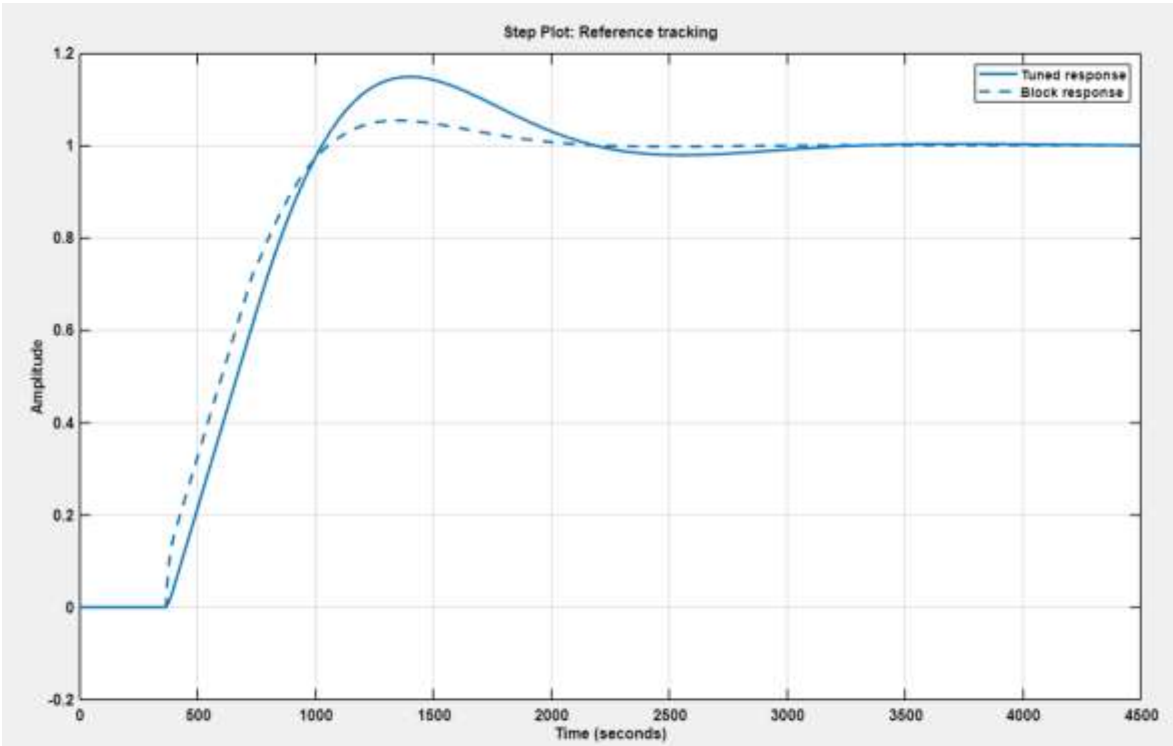


Figure set point tracking for 5th tuning