Design of Water Heater Temperature Control System using PID Control

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Abstract— **This research delves into advanced control methodologies by investigating the intricate applications of Proportional-Integral-Derivative (PID) control for achieving precise and dependable temperature regulation within electric water heaters. The study delves into various control strategies, namely Proportional, Proportional-Integral, and Proportional-Integral-Derivative methodologies, to realize the pinnacle of stable and exacting temperature control. The Proportional Controller, operating with a Kp value of 10, stands out with its relentless performance, characterized by minimal overshoot and an inconsequential steady-state error. Implementing the Proportional-Integral Controller, synergizing Kp at 10 and Ki at 5, elevates system stability while deftly curbing any hint of overshoot. The dynamic interplay between the Kp, Ki, and Kd parameters in the Proportional-Integral-Derivative (PID) Controller unveils an intricate dance of precision and control. Notably, configurations involving Kp 10, Ki 5, and Kd 2 emerge as beacons of rapid stabilization, heightened precision, and masterful overshoot management, exemplified by a rise time of 119.3543 seconds, settling time of 162.6116 seconds, overshoot of 1.0299%, peak time of 216 seconds, and a commendably low steady-state error of 0.31. This extensive exploration bears testament to its instrumental role in optimizing PID control strategies, ushering in augmented efficacy and pinpoint accuracy in water temperature regulation across an expansive spectrum of applications. As a result, these findings pave the way for the evolution of control methodologies that transcend theoretical confines and manifest within practical scenarios with profound impact.**

Keywords—***DS18B20, Arduino, Water Heater, PID***

I. INTRODUCTION

Electric heaters are electronic devices that convert electrical energy into heat energy. A resistor [1] is the heating element present in electric heaters [2], [3]. Electricity is transformed into heat energy when an electric current flows through the resistor [1]. Liquid heating is a form of electrical heating where specific fluids are heated to predetermined temperatures as needed. Liquid heating finds applications in various fields, including industries, research, and households. Temperature control is essential in several industries and applications, such as maintaining the ideal water temperature for different types of fish [4]–[6], achieving the perfect temperature for coffee [7], [8], and ensuring a comfortable bathwater temperature [9], [10], aquaponic [11], [12], and temperature control for baby incubator [13]. Water is one of the most commonly used substances in various liquid heating applications.

Adapting to different applications, liquid heating requires accurate temperature adjustments as a function of time. These adjustments can vary, and the work of the actuator needed also varies based on the desired power output. Some water heaters have thermostats that provide discrete control (on/off) and require human operators for manual operation or automatically [14], [15]. However, PID (Proportional Integral Derivative) control offers analog control capable of continuously and precisely regulating the power output of a heater as needed. With this control system, water heating that demands excellent temperature accuracy concerning time can be automated effectively. The process can be carried out efficiently and accurately during the heating and temperature-holding phases. The PID control system provides continuous analog control, reducing the need for manual intervention [16].

Prior research has addressed the thermal stabilization of water heater dispensers through diverse approaches. A notable methodology involves the application of Ziegler-Nicholas PID tuning, resulting in the achievement of a peak temperature of 92.62°C within 34 minutes, alongside prompt attainment of a water temperature of 65°C in 8 minutes (480 seconds) [17]. A thermoelectric portable water heater has been developed in a separate study, employing a power bank as the energy source. Notably, this investigation attains a maximum water temperature of 34°C within 15 minutes (900 seconds), omitting the utilization of PID control [18].

Considering the background presented above, the authors recognize the importance of understanding how PID controllers can be applied to electric water heaters and how proper PID tuning can be implemented in PID controller-based electric water heaters. Therefore, this research involves the development of a prototype and experimentation on "Design of Water Heater Temperature Control System using PID Control" where a 12 Volt immersion water heater with a power of 120 Watts is employed as the actuator, and a waterproof DS18B20 temperature sensor is used for temperature measurement.

II. METHODS

This research calibrated the heater's temperature using a standardized thermometer, and optimal PID parameters were determined for precise and continuous control. The research aims to achieve stable temperature control, which is vital in various applications, enhancing process efficiency and reliability. Experimental results will advance PID implementation in heating systems.

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A. *Diagram Block*

This research implements an Arduino-based water temperature control system using a water heater to achieve precise temperature stabilization at the desired level. The system maintains well-responsive and stable temperature control using a Proportional-Integral-Derivative (PID) controller. The research aims to demonstrate the effectiveness of PID control in achieving reliable and efficient temperature regulation in water heating systems. Fig. 1 shows The Diagram Block System

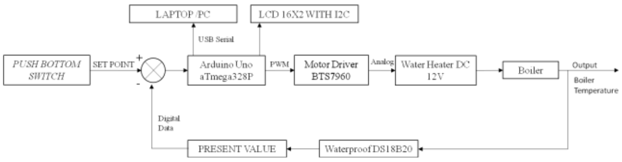

Fig. 1. Diagram block system

In this research, the input system is depicted in Fig. 1, utilizing a Push Button as the setpoint input. To enhance user experience, a user interface comprising an LCD 16x2 display is implemented to control the water heater temperature effectively. The Arduino Uno microcontroller regulates the entire system, ensuring seamless integration of the components. The PWM controller BTS 7960 plays a pivotal role in managing the power output of the water heater, enabling efficient temperature control. Furthermore, a 12V water heater is employed as the heat source to raise the water temperature in the system. The DS18B20 temperature sensor monitors and stabilizes the water temperature, serving as a crucial feedback mechanism for the PID system. Combining these components and utilizing the PID control approach, the system can achieve precise and consistent water temperature regulation, making it suitable for various industrial and research applications.

B. *Wiring Diagram*

The Water Heater Temperature Control System is integrated with the Arduino Uno 328P microcontroller as its primary computing unit. The system features four push buttons, a BTS7960 module, and auxiliary components, including a power supply, step-down module, DS18B20 temperature sensor, and an LCD 16x2 display. The Arduino Uno 328P is the central control hub, receiving input signals from the push buttons and DS18B20 sensor and effectively managing the output control to the BTS7960 and LCD. This arrangement enables the system to regulate the water heater's temperature precisely and efficiently during heating. For a visual representation of the system's wiring connections, refer to Fig. 2 Wiring Diagram. Arduino-based control in the Water Heater Temperature Control System enhances its responsiveness and accuracy, offering practical applications in various industrial and research settings.

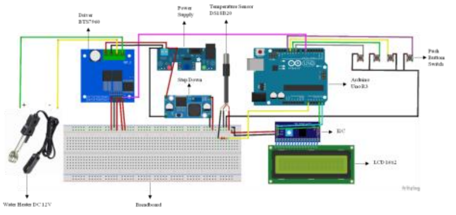

Fig. 2. Wiring diagram

C. *Flowchart System*

In this research, the flowchart process illustrated in Fig. 3 involves the initialization of essential parameters for the PID controller, namely the Set Point, Proportional Gain (Kp), Integral Gain (Ki), and Derivative Gain (Kd). Once initialized, the system proceeds to read the water temperature condition and computes the temperature error in relation to the desired set point. Subsequently, the PID calculation is executed, and its resulting value is utilized as the input for Pulse Width Modulation (PWM), which governs the water heater's power output. The system will remain in operation if the conditions are met; however, it will halt when the state becomes false (0). This comprehensive flowchart provides a visual representation of the sequential steps involved in the PID-based water temperature control system, ensuring precise and responsive regulation of the water heater, which is crucial for numerous industrial and research applications. The implementation of PID control enhances temperature stability and maintains the desired set point efficiently, leading to optimized performance and enhanced process control in various domains.

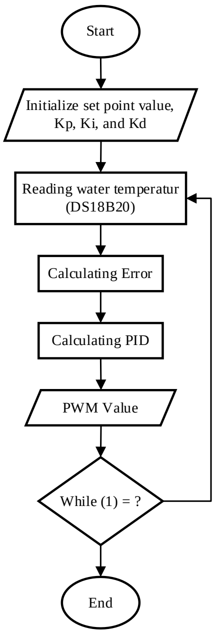

Fig. 3. Flowchart system

D. *System Diagram*

Fig. 4 illustrates the System diagram of a systematic tool designed for real-time water temperature monitoring during water heating. The system incorporates a 12V DC water heater for elevating the water temperature and a DS18B20 sensor to detect and record the precise water temperature values. Upon reaching a predetermined set point, the system seamlessly engages an automated mechanism to regulate and sustain the water temperature at the desired level. This control mechanism can encompass either the pulse-width modulation (PWM) signal or the implementation of a feedback loop. Subsequently, the system displays the designated set point value on the user interface, predominantly involving the operation of a Laptop through the Arduino Integrated Development Environment (IDE) alongside a 16x2 LCD. This comprehensive interface provides users a convenient means to access and comprehend crucial temperature information, facilitating efficient monitoring and control of the water heating process.

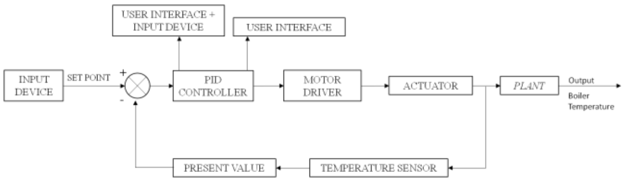

Fig. 4. System diagram

E. PID

The Proportional Integral Derivative (PID) controller is a feedback control mechanism commonly employed in industrial control systems [19]. A PID controller continuously calculates the error as the difference between the desired setpoint and the measured process variable. It strives to minimize the error value over time by adjusting control variables, such as control valve position, damper opening, or heating element power, to new values determined by the PID controller's equation (1) [20].

$$u = K_p e(t) + \frac{K_p}{T_i}\int_0^t e(t)dt + K_p T_d \frac{de(t)}{dt} \tag{1}$$

In the control system, Kp represents the proportional constant, Ki represents the integral constant, and Kd represents the derivative constant, all of which are essential parameters in the Proportional-Integral-Derivative (PID) control algorithm widely used in regulating and stabilizing various industrial processes [21]. The proportional constant (Kp) determines the control action's magnitude in proportion to the error signal, the integral constant (Ki) acts on the integral of the error signal over time, and the derivative constant (Kd) influences the rate of change of the error signal. By fine-tuning these PID constants, the system's response and stability can be optimized, leading to efficient and accurate control of dynamic systems in engineering and industrial applications. The parameter P responds to the current error measurement, where a significant positive error value results in a sizeable positive control output. The parameter I address the accumulated error from past periods, and if the current output is too low, the error will accumulate, prompting the controller to respond with a higher result. Parameter D is responsible for predicting future errors based on the rate of change over time. These PID parameters facilitate robust and precise control, enabling advanced applications in diverse industries.

The PID controller's ability to continuously analyze and adjust control variables enables precise and efficient control in various industrial processes. By considering the present error, past accumulated error, and future error prediction, the PID controller can maintain the system at the desired setpoint, effectively regulating the process and enhancing overall system performance. The PID control approach has proven to be an essential tool in industrial automation, offering stability, accuracy, and adaptability in controlling complex systems across different applications.

F. System Response

System response is the system's response from the initial state to the steady-state condition. In contrast, steady-state response refers to the output condition after the system response has ceased until a relatively infinite time. The characteristics of a control system's quick response to a step input can generally be expressed as follows. Peak Time (tp) refers to the time the responsive system takes to reach the first peak of the overshoot takes. Rise Time (tr) indicates the duration required by the responsive system (output) to reach the final value (or encompass the range between 10% to 90% of the final value). Undershoot describes the condition where a signal or function has a value lower than the reference (set point) value.

The maximum overshoot, Mp, represents the maximum value of the peak response calculated relative to the value of one. The maximum overshoot is usually expressed as a percentage of the responsive system achieving stability. The value of overshoot in percentage is calculated using the equation (2):

$$Mp = \frac{c(tp) - c(\infty)}{c(\infty)}\ x\ 100\% \tag{2}$$

In this context, $c(tp)$ represents the value of the maximum overshoot, and $c(\infty)$ refers to the value when the system reaches a steady-state condition. The maximum amount of overshoot indicates the level of system stability. A stable system will have an overshoot that does not exceed 10%. Delay Time (TD) is required for the system response to reach half the final value for the first time. Settling time (Ts) describes the time the system output reaches and remains within its steady-state value (± 2% of the final value). Steady-state error is the difference between the desired final value (set point) and the actual final value when the system reaches the steady-state condition. Understanding these system response characteristics is crucial in analyzing and designing control systems to achieve desired performance and stability.

III. RESULTS AND DISCUSSION

This research delves into water temperature control in a water heater, focusing on evaluating PID methods. The study examines the time efficiency and heat response achieved through PID implementation. Throughout the investigation, a meticulous analysis of PID parameters and their impact on the water heater's performance is conducted, aiming to gain comprehensive insights into the efficacy and dependability of the PID Controller in regulating water heater temperatures. The findings from this study will contribute to advancing the knowledge and practical application of PID control techniques for water heating systems, ultimately enhancing their efficiency and reliability in various domains.

A. Temperature Sensor

The temperature sensor testing commenced with the calibration of the sensor using a standardized thermometer. Throughout this phase, the sensor underwent testing under diverse temperature conditions, spanning from 34.5 degrees Celsius to 41.7 degrees Celsius, aligning with the maximum measurement capacity of the standardized thermometer. Table 1 presents the outcomes obtained from the calibration test, showcasing the correlation between the temperature sensor readings and the readings obtained from the standardized thermometer.

Table 1. Temperature calibration

Thermometer	Sensor	Error
34.5°C	34.5°C	0°C
35.8°C	35.9°C	0.1°C
36.9°C	36.9°C	0°C
37.5°C	37.5°C	0°C
37.9°C	38.0°C	0.1°C
38.6°C	38.7°C	0.1°C
39.8°C	39.7°C	0.1°C
40°C°C	40°C	0°C
40.5°C	40.5°C	0°C
41.7°C	41.7°C	0°C

A comparative evaluation was conducted using Table 1, where the DS18B20 temperature sensor was simultaneously tested alongside a standard thermometer. The results demonstrated that the DS18B20 sensor provided precise temperature measurements with a minimal deviation ranging from 0 to 0.1°C. This outcome confirms the sensor's accuracy and suitability for research purposes, ensuring reliable temperature data collection throughout the study. The use of the DS18B20 sensor contributes to the scientific rigor and credibility of the research, enabling robust analysis and conclusions in temperature control and monitoring.

B. Water Heater

In this section, the water heater was tested utilizing the PWM Controller BTS7960 with PWM value of 225. The experiments were performed with a water volume of 300 mL, which was 25 minutes, ultimately achieving a temperature of 68°C. The PWM controller allowed precise control over the power output to the water heater, enabling efficient and accurate temperature regulation within the specified time frame. The obtained results provide valuable insights into the performance and effectiveness of the PWM Controller BTS7960 driver in achieving the desired water temperature for this research.

C. Proportional Controller

In this experimental research, we implemented and tested the Proportional Controller on the water heater system. We maintained a zero value on Ki and Kd parameter. However, to observe the response of the Proportional Controller in the water heating system, we varied the Kp parameter. We set the test duration to 525 seconds and selected the experiment's Kp parameter values of 10, 20, and 50. The Proportional Controller testing results for the water heating system are shown in Fig.5, offering valuable insights into the system's performance under different Kp settings.

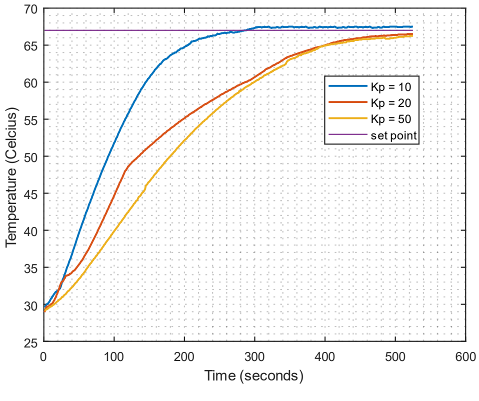

Fig. 5. Proportional controller response system

Table 2 presents a comprehensive exposition of the dynamic response characteristics of the Proportional Controller, a key component in control systems, evaluated across varying Proportional Constant (Kp) values. This meticulous analysis within a controlled experimental framework delineates critical performance metrics, including settling time, rise time, overshoot, peak time, and steady-state error. These metrics are pivotal in elucidating the Proportional Controller's behavior and efficacy in regulating temperature control processes.

Table 2. Response system proportional controller

Kp	Settling Time (s)	Rise Time (s)	Overshoot (%)	Peak Time (s)	Steady State Error(°C)
10	240.040	149.1611	0.7463	314	-0.5
20	476.813	319.0827	0	517	0.5
50	520.896	308.2250	0	521	0.75

The Proportional Controller, driven by the Kp value, which governs the proportional gain in relation to the error signal, manifests distinct response patterns as Kp values vary. Settling time, an indicator of the duration for the system to attain stability within a specified range of the desired setpoint demonstrates an intriguing trend across Kp values of 10, 20, and 50. A lower Kp value, such as 10, corresponds to a notably shorter settling time of 240.040 seconds, indicating a rapid convergence to the desired temperature.

Rise time, denoting the time interval required for the system's output to transition from a certain percentage of the setpoint to another, offers insights into the controller's speed of response. The table unveils a discernible relationship between Kp and rise time. As Kp augments, rise time elongates, as evidenced by Kp 50's rise time of 308.225 seconds, while Kp 10 showcases a substantially shorter rise time of 149.1611 seconds.

Overshoot, a parameter quantifying the extent of transient deviation beyond the desired setpoint, portrays an interesting observation across the tested Kp values. Kp 10 displays a modest overshoot of 0.7463%, implying a balanced compromise between responsiveness and overshoot magnitude. Remarkably, the absence of overshoot in the system's response at Kp 20 and Kp 50 underscores the effectiveness of these proportional gain values in achieving a precise and stable temperature control without initial oscillations or deviations from the desired setpoint.

Peak time, reflecting the time taken for the system's initial peak response during transient behavior underscores the impact of Kp on the controller's agility. Higher Kp values, such as 50, yield marginally longer peak times of 521 seconds. In contrast, Kp 10 and Kp 20 exhibit notably shorter peak times of 314 and 517 seconds, respectively, suggesting their quicker attainment of peak response.

Steady-state error, which measures the sustained deviation of the system's output from the desired setpoint once equilibrium has been achieved, further delineates the controller's effectiveness. Kp 10 demonstrates the smallest steady-state error of -0.5°C, signifying its ability to maintain the set temperature closely. On the other hand, Kp 20 and Kp 50 exhibit steady-state errors of 0.5°C and 0.75°C, respectively.

The analysis of the dynamic response characteristics of the Proportional Controller across varying Proportional Constant (Kp) values, as presented in Table 2, offers valuable insights into its efficacy in regulating temperature control processes. The study underscores that a Kp value 10 leads to a notably shorter settling time, quicker rise time, modest overshoot, and the smallest steady-state error, indicating its ability to achieve rapid convergence to the desired temperature with precise control and minimal deviations. This comprehensive evaluation suggests that a Kp value 10 is optimal for maintaining stable and accurate temperature control, with other tested values showing trade-offs between responsiveness and performance metrics. These findings hold significant implications for enhancing temperature control strategies across various practical applications.

D. Proportional Integral Controller

In this experimental study, we implemented and tested the Proportional Integral Controller on the water heater system. We maintained a fixed Kp value of 10 and a Kd value 0. However, to observe the response of the Integral Controller in the water heating system, we varied the Ki parameter. We set the test duration to 250 seconds and selected the experiment's Ki parameter values of 1, 5, and 7. The Proportional Integral Controller testing results for the water heating system are depicted in Fig. 6, offering valuable insights into the system's performance under different Ki settings. Additionally, Table 3 presents the comprehensive response system results for the Proportional Integral Controller.

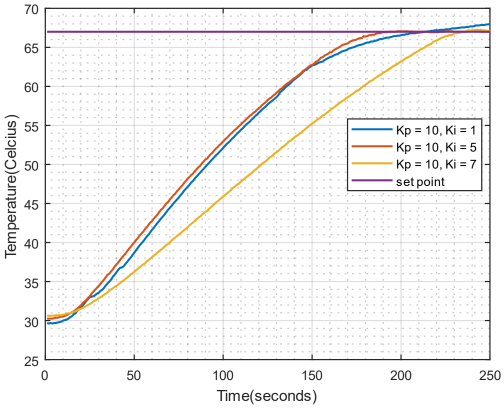

Fig. 6. Proportional integral controller system

Table 3 presents a comprehensive assessment of the Proportional Integral Controller (PIC) tests conducted on the water heater system, where the Proportional Constant (Kp) and Integral Constant (Ki) were systematically varied to investigate the system's response under diverse control parameter configurations. The outcomes offer crucial insights into the system's behavior, encompassing stability, response speed, overshoot, peak time, and steady-state error.

Table 3. Response system proportional integral controller

Kp	**Ki**	**Settling Time (s)**	**Rise Time (s)**	**Overshoot (%)**	**Peak Time (s)**	**Steady State Error(°C)**
10	1	NaN	127.5158	1.4925	250	-1
20	5	178.3000	125.4547	0.0896	198	0
50	7	223.3733	126.5626	0.3731	242	-0.06

In the first configuration with Kp set to 10 and Ki set to 1, a significant limitation in system stabilization was evident, leading to an undefined settling time (“NaN”). The rise time measured at 127.5158 seconds and an overshoot of 1.4925% indicated a temporary deviation beyond the desired setpoint during stabilization. Additionally, the system consistently undershot the desired setpoint, as demonstrated by the steady-state error of -1.

Moving to the second configuration with Kp set to 20 and Ki set to 5, the system showcased successful stabilization with a settling time of 178.3000 seconds. The improved rise time of 125.4547 seconds indicated more efficient temperature attainment compared to the previous configuration. Moreover, the minimal overshoot of 0.0896% highlighted a stable response close to the desired setpoint. The peak time was approximately 198 seconds, and the steady-state error was 0, signifying effective maintenance of the desired setpoint without deviation.

The third configuration, Kp set to 50 and Ki set to 7, demonstrated relatively rapid stabilization with a settling time of 223.3733 seconds. The rise time remained comparable to the previous configuration, at 126.5626 seconds. An observed overshoot of 0.3731% indicated a minor transient peak during stabilization, while the peak time was approximately 242 seconds. The steady-state error of -0.06°C indicated a slight undershoot from the desired setpoint.

The analysis of the Proportional Integral (PI) Controller tests presented in Table 3 offers insightful guidance for selecting optimal control parameters in the context of a water heater system. Among the tested configurations, the second setup with Kp set to 20 and Ki set to 5 emerges as the most effective. This configuration demonstrated successful stabilization with a reasonable settling time, improved rise time, minimal overshoot, and accurate maintenance of the desired setpoint. These attributes collectively signify a controlled and precise temperature regulation process. The results emphasize the importance of carefully balancing the Proportional (Kp) and Integral (Ki) constants for optimal system performance, with the Kp value of 20 and Ki value of 5 offering the best compromise between response speed and stability. These findings are valuable for enhancing control strategies in various practical applications necessitating accurate temperature regulation.

E. Proportional Integral Derivative (PID) Controller

We conducted the experimental endeavor with meticulous precision in the PID controller evaluation. The Kp value remained unwavering at 10, while we kept the Ki parameter resolute at 5, providing a consistent backdrop against which we deftly manipulated the enigmatic Kd parameter. This probing exploration transpired across a carefully stipulated temporal expanse of 300 seconds, within which a thorough assessment of the PID controller's comportment materialized, orchestrated through the systematic variation of Kd values, specifically 1 and 2. The graphical depiction seen in Fig. 7 eloquently elucidates the zenith of these empirical investigations, serving as a visual testament that intricately captures the system's nuanced oscillations and behaviors. It dynamically responds to the distinct and multifarious Kd configurations.

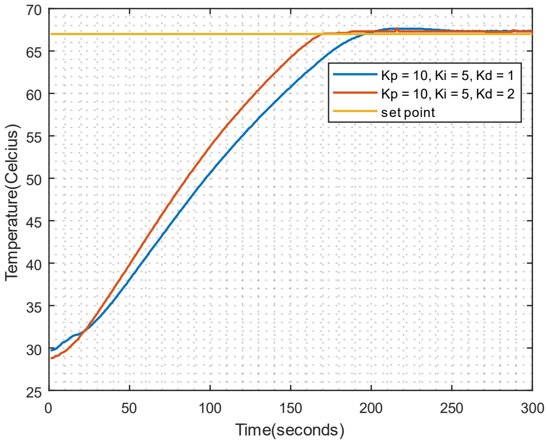

Fig. 7. PID Controller System

Table 4 presents an intricate examination of the PID Controller experiments, elucidating the impact of the Proportional Constant (Kp), Integral Constant (Ki), and Derivative Constant (Kd) on the operational performance of the water heater system. This array of variables plays a pivotal role in unraveling the intricate interactions between control parameters and their consequential effects on crucial facets of the system's behavior.

Table 4. Response system PID controller

Kp	Ki	Kd	Settling Time (s)	Rise Time (s)	Overshoot (%)	Peak Time (s)	Steady State Error(°C)
10	5	1	186.0633	134.5444	0.9254	211	-0.31
10	5	2	162.6116	119.3543	1.0299	216	-0.31

In the initial configuration, characterized by Kp, Ki, and Kd values of 10, 5, and 1, respectively, the system showcased a settling time of 186.0633 seconds, indicative of the temporal interval required to attain stability and the rise time, quantified at 134.5444 seconds, elucidated the duration for the system to reach its ultimate value. A marginal overshoot of 0.9254% was discerned, implying a relatively stable response. The peak time registered approximately 211 seconds, and the steady-state error was reported at -0.31, indicating a modest divergence from the desired setpoint during stabilized conditions.

In the subsequent configuration, Kp and Ki remained constant at 10 and 5, respectively. At the same time, Kd was adjusted to 2, and a reduced settling time of 162.6116 seconds was observed, indicating expedited stabilization, and the diminished rise time of 119.3543 seconds signified an improved precision in temperature convergence. A slightly elevated overshoot of 1.0299% was recorded, denoting a transient peak deviation. The peak time was approximately 216 seconds, and the steady-state error consistently remained at -0.31, emblematic of a consistent minor variation from the desired setpoint.

Table 4 encapsulates the intricate interplay among Kp, Ki, and Kd within the PID Controller framework. This exhaustive analysis deepens our comprehension of how these parameters synergize to mold the water heater system's dynamics, thereby providing pivotal insights for refining PID control strategies and enhancing the system's overall efficiency and precision across a diverse spectrum of practical applications.

Optimal parameter configuration of Proportional-Integral-Derivative (PID) controllers plays a pivotal role in achieving precise and stable temperature regulation across diverse applications. This experimental inquiry comprehensively explored the efficacy of various control strategies, encompassing Proportional, Proportional-Integral, and Proportional-Integral-Derivative approaches. Particularly noteworthy, the Proportional Controller demonstrated remarkable performance with a Kp value 10, showcasing stable and rapid responses coupled with minimal overshoot and an almost negligible steady-state error. The Proportional-Integral Controller, configured with Kp set at 10 and Ki at 5, yielded favorable outcomes, emphasizing stability and marginal overshoot. Moreover, the intricate interplay of Kp, Ki, and Kd parameters in the Proportional-Integral-Derivative Controller unveiled multifaceted dynamics. Among the tested configurations, the Kp 10, Ki 5, and Kd 2 combination exhibited expedited stabilization, heightened precision, and a controlled overshoot. This all-encompassing analysis substantially contributes to optimizing PID control strategies, thereby elevating the efficiency and accuracy of water temperature management systems across a wide spectrum of applications, effectively advancing control methodologies for real-world scenarios.

IV. CONCLUSION

Implementing a PID controller for electric water heaters entails the establishment of a meticulously designed operational framework encompassing essential components. This involves meticulously selecting actuators, sensors, controller devices, drivers, and signal conditioning elements. In the present experiment, a 12 Volt DC immersion water heater, boasting a power output of 120 Watts, serves as the designated actuator. At the same time, the DS18B20 waterproof sensor fulfills the role of the sensor. The control system hinges on utilizing the Arduino Atmega328P as the controller device and the BTS7960 motor driver for actuation, all achieved without necessitating hardware signal conditioning.

The precise tuning of the PID parameters hinges on the unique demands and objectives of the water heating application. Irrespective of the specific context, the calibration of PID gains (Kp, Ki, and Kd) necessitates a thorough understanding of their respective contributions and influences. In the prototype developed within this experimentation, achieving a response characterized by the swiftest rise time, rapid settling time, overshoot value, and maintaining high stability is attained by employing a PID control configuration with Kp set at 10, Ki at 5, and Kd at 2.

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