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Application of Proportional Integral Derivative (PID) Control in Overvoltage Protection Systems for Low Voltage Network Loads

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Abstract *− Electricity is a very essential need for every element of society in this modern era, with electricity, various kinds of work can be easily done. However, in electricity distribution, there are often disturbances that can be detrimental to consumers. One of the power lines that usually experiences interference is the Low Voltage Network line. Low voltage network is a transmission network with a low voltage classification between 220 volts and 280 volts. In this transmission, various kinds of disturbances often occur, such as overvoltage and voltage drops. In this research, the author discusses the overvoltage protection system using Proportional Integral Derivative (PID) control. PID control is a simple control method that several researchers have developed to overcome various electrical problems in this modern era. For this reason, the researcher will develop PID as a protection system to overcome overvoltage disturbances in low voltage network transmissions. The appropriate PID parameter value to overcome overvoltage in this study is the value* $K_p = 5$*;* $K_i = 0.3$*;* $K_d = 0.01$*, where the system is able to protect the overvoltage according to the setpoint value 220 volts.*

Keywords − *Overvoltage protection; PID control; Low voltage network; Electrical disturbances; Voltage regulation.*

I. Introduction

ELECTRICITY is an essential requirement for living in the contemporary day, facilitating the efficient execution of tasks that necessitate electrical energy. Electrical utilization may result in losses if there is an interruption in the electrical distribution network. Common issues include overvoltage disturbances and voltage drops, which can damage loads such as electronic gadgets and other equipment reliant on electrical energy.

Common obstacles include fluctuations in electrical voltage, including overvoltage and undervoltage. If this voltage issue pertains to electrical or electronic devices and beyond the nominal voltage tolerance threshold, it may impair the functionality of the equipment or cause damage to it [1]. A low voltage network is required to link an electricity supply directly to users' residences. The Low Voltage Network is a transmission system classified by a voltage range of 220 volts to 380 volts. This network comprises a coil and a core; the core of the low voltage network generates a magnetic field that induces a secondary coil, subsequently producing an electric voltage.

The voltage generated by the main substation will be decreased prior to distribution to users' residences through Home Channels. The fluctuation in the number of electricity consumers results in variations in power generation; an increase in consumers leads to a decrease in power, while a fall in power results in an increase in voltage. Among these two disturbances, overvoltage disturbances frequently arise in low voltage network transmissions. Overvoltage disturbances are disruptions that frequently arise in low-voltage network systems [2]. To maintain the voltage on the network within acceptable limits, it is essential to regulate the voltage by either increasing it or decreasing it if it is excessively high [3]. A protective mechanism is essential for the low voltage network safety. The protective system is among the most critical components in the realm of electricity.

The protection system is employed to ensure the continuity of electric power distribution and safeguard both electrical network apparatus and electrical loads or consumers against interruptions [4]. A controller is required to detect voltage fluctuations on the low voltage network to mitigate overvoltage and prevent

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damage to the load [5–10]. The Proportional Integral Derivative (PID) controller is one of the most often employed methods for regulating electrical systems.

The PID is a control methodology characterized by its straightforward design, extensively employed to address issues in diverse electrical equipment. PID (Proportional-Integral-Derivative) control is a widely used and versatile control methodology in various industrial applications due to its simplicity, effectiveness, and ease of implementation [11,12]. It is estimated that over 90% of control loops employ PID control [11]. PID controllers are extensively used in diverse electrical equipment, including DC motors, power systems, and automation systems [13,14]. The popularity of PID control in industry is attributed to its straightforward design and tuning process [15]. Recent research has focused on improving PID control through advanced tuning methods, adaptation techniques, and integration with artificial intelligence [13, 16]. PID control has demonstrated its continued relevance and adaptability in addressing modern control challenges across various sectors, including manufacturing, chemical processes, and power systems [17, 18]. The PID control approach is a solution to address complexity in control circuits [19–28]. The author suggests employing PID control to address overvoltage issues in protection systems for low voltage network loads.

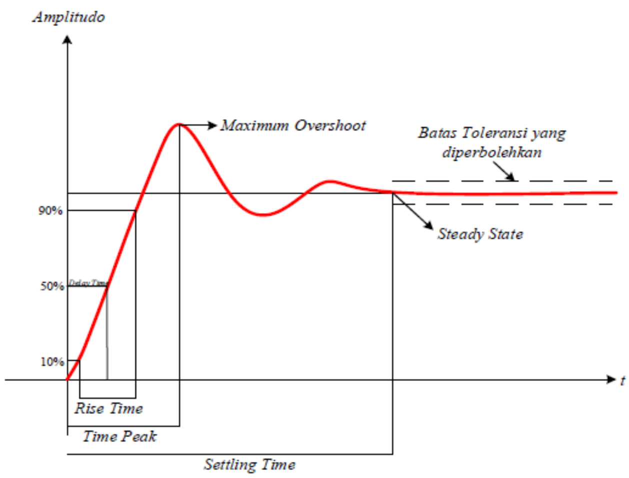


Figure 1: Graph of System Response Displaying t_d, t_r, t_p, M_p, t_s, E_{ss}

Figure 1 illustrates the configuration of the PID signal output that will be utilized in the investigation.

1. 50% of the first instance upon attaining the designated set point (delay time), t_d
2. The rise time is defined as the duration required for the system to achieve 10%-90% of the set point (rise time), t_r
3. The moment it attains the apex (peak time), t_p
4. The error value that arises during overshoot (maximum overshoot), M_p
5. Duration necessary to attain the set point (settling time), t_s
6. Steady-state error value (steady state error), E_{ss}

II. Research Methods

The research involved assembling various components, which were subsequently engineered into a device capable of safeguarding against overvoltage. The necessary components include an Arduino Uno, a dimmer, a voltage sensor, and jumper cables. Software is required in the form of an Arduino IDE application to input the program into the device and a MATLAB application to interpret the output signal results from the device. The research process commences with a literature review, followed by system design, program design, system testing, analysis, and conclusions.

Literary studies are conducted by utilizing material from several credible sources pertinent to the research topic, including books, journals, and theses authored by other scholars. System design involves the creation and development of tools in accordance with the research plan. Program design involves developing a programming language that is subsequently integrated into the Arduino via the Arduino IDE application.

System testing involves evaluating the voltage protection device to determine if it has been effectively developed by analyzing the voltage output results and its capability to safeguard the voltage at the specified set point. Analysis and conclusions consist of acquired data subjected to comprehensive examination, leading to inferences based on the results of the data collection.

i. Arrangement of Systems

The goal of the system design is to facilitate researchers' tool-making process.

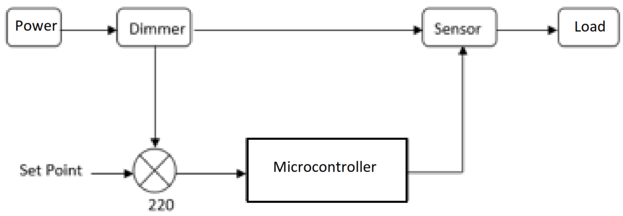


Figure 2: System Block Diagram

Figure 2 illustrates a concept for an overvoltage protection system utilizing a PID, incorporating low voltage network as a voltage reference and a dimmer as a switch capable of disconnecting the electricity in the event of an overvoltage condition. Utilize a voltage sensor to detect the presence of voltage entering the circuit, establishing a load as an output of voltage and a setpoint. The microcontroller serves as the overvoltage protection processor in the system, determining the input voltage value detected by the voltage sensor.

The system operates by allowing voltage from the source to flow directly to the load dimmer. When the voltage reaches the tolerance threshold of 220 volts, the system does not process this voltage. However, if the voltage exceeds this limit, the dimmer will reduce the electrical voltage accordingly. The electric voltage will be transmitted to the sensor, subsequently adjusted by the setpoint, and then processed by the PID controller, with the output directed to the dimmer and load.

ii. System Evolution

System testing is conducted to evaluate the output findings from the tool, determining whether it functions well and fulfills the researcher's objectives. Testing commences by integrating all components into a singular interconnected unit to mitigate overvoltage.

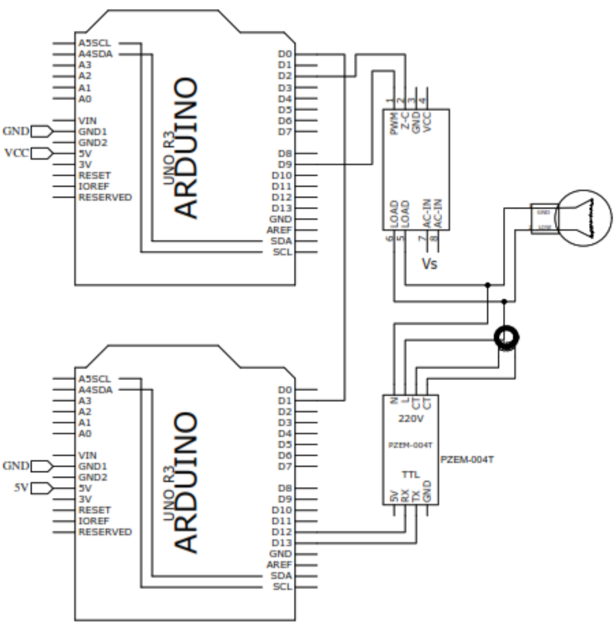


Figure 3: Testing Network

Figure 3 illustrates a schematic of the component circuit designed as an overvoltage protection device for a low voltage network distribution system, comprising two Arduino UNOs. The Arduino linked to the dimmer functions as the receiving unit, while the Arduino connected to the voltage sensor serves as the transmitting unit, along with the dimmer, voltage sensor, and lights as system outputs.

The device operates by transmitting the incoming voltage to the voltage sensor via the dimmer. When the voltage surpasses the designated threshold, the transmitting Arduino will relay the sensor readings to the receiving Arduino, which will then instruct the dimmer to terminate the electrical voltage signal, aligning the results with the setpoint.

III. Results and Discussion

This part examines the outcomes of testing the voltage protection system, designed to ascertain its operational status and compliance with the study parameters.

i. Testing of PID Systems

At this point, the system undergoes comprehensive testing by integrating all components and employing the PID approach, specifically by randomly determining the K_p, K_i, and K_d values until the appropriate PID parameters are identified to safeguard against overvoltage. The established PID parameters are anticipated to effectively mitigate the overvoltage present in the Low Voltage Network. The source voltage utilized in this test is 240 V, with a setpoint established at 220 V.

ii. System Evaluation Kp = 0.8, Ki = 0.5, Kd = 0.055

Conducting tests with parameters $K_p = 0.8$, $K_i = 0.5$, $K_d = 0.055$. Acquired values: delay time = 0.15 seconds, rising time = 3.8 seconds, peak time = 13.7 seconds, maximum overshoot = 1.36%, settling time = 5.8 seconds, and steady-state error = 3%.

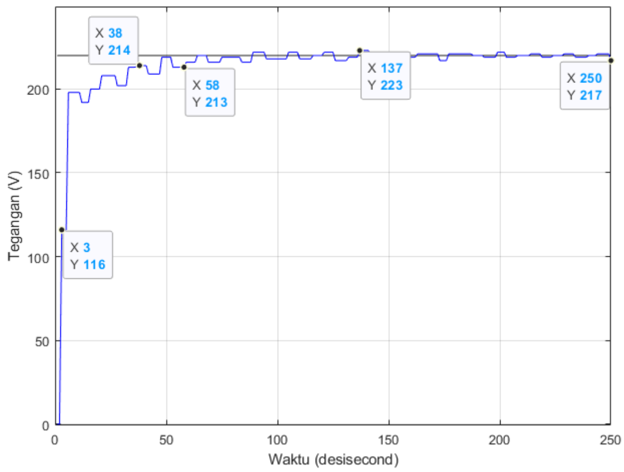


Figure 4: Graph of system reaction with $K_p = 0.8$, $K_i = 0.5$, $K_d = 0.055$

Figure 4 indicates that the system can mitigate overvoltage; however, voltage stability remains elusive. Consequently, it is imperative to adjust the PID control parameters to get the required aim.

iii. System Testing with Kp = 1, Ki = 0.4, Kd = 0.03

Conduct a test with K_p value set to 1, K_i at 0.4, and K_d at 0.03. Acquired values: delay time = 0.65 seconds, rising time = 13.89 seconds, peak time = 2.7

seconds, maximum overshoot = 2.72%, settling time = 3.6 seconds, and steady-state error = 0%.

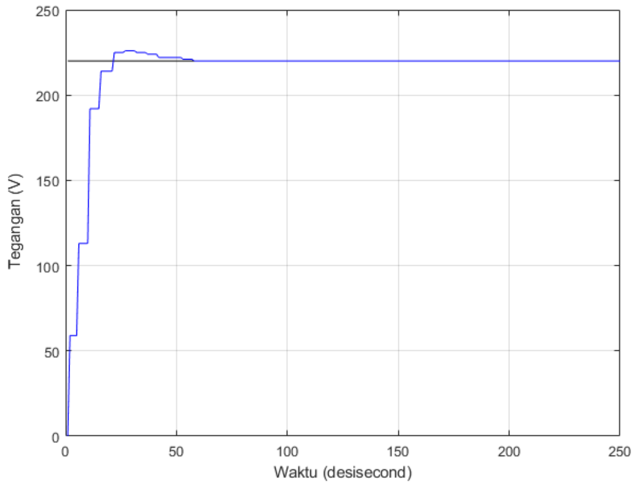


Figure 5: Graph of system reaction with $K_p = 1$, $K_i = 0.4$, $K_d = 0.03$

In the test depicted in Figure 5, the system successfully diminished the voltage; nonetheless, an overshoot persisted.

iv. System Testing with Kp = 3, Ki = 0.4, Kd = 0.01

Testing with $K_p = 3$, $K_i = 0.4$, $K_d = 0.01$ yielded a delay time of 0.2 seconds, rising time of 1.3 seconds, peak time of 13.6 seconds, maximum overshoot of 1.81%, settling time of 5.2 seconds, and steady-state error of 0%.

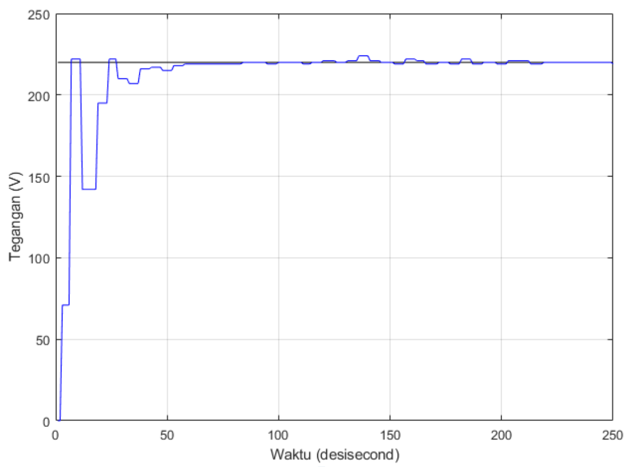


Figure 6: Graph of system reaction with $K_p = 3$, $K_i = 0.4$, $K_d = 0.01$

Figure 6 illustrates that the system has successfully diminished the voltage; nonetheless, oscillatory overshoot persists.

v. System Evaluation With Kp = 5, Ki = 0.3, Kd = 0.01

The test yielded a delay time of 0.35 seconds, a rising time of 0.7 seconds, a peak time of 0 seconds, a maximum overshoot of 0%, a settling time of 8.6 seconds, and a steady-state error of 0%.

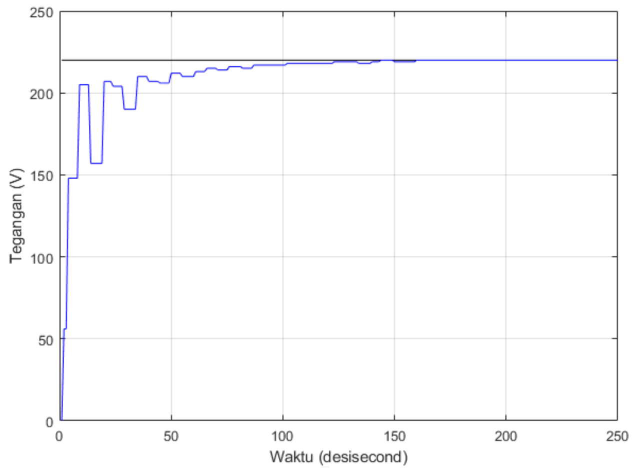


Figure 7: Graph of system reaction with $K_p = 5$, $K_i = 0.3$, $K_d = 0.01$

According to Figure 7, the system effectively reduces the voltage without any overshoot, maintaining stability at 220 V.

vi. System Testing with Kp = 7, Ki = 0.5, Kd = 0.05

Conducting tests with parameters $K_p = 7$, $K_i = 0.5$, $K_d = 0.05$ yielded values: delay time = 0.1 seconds, rising time = 1.4 seconds, peak time = 16.4 seconds, maximum overshoot = 8.16%, settling time = 20.9 seconds, and steady-state error = 2%. At this level, the system continues to exhibit oscillations.

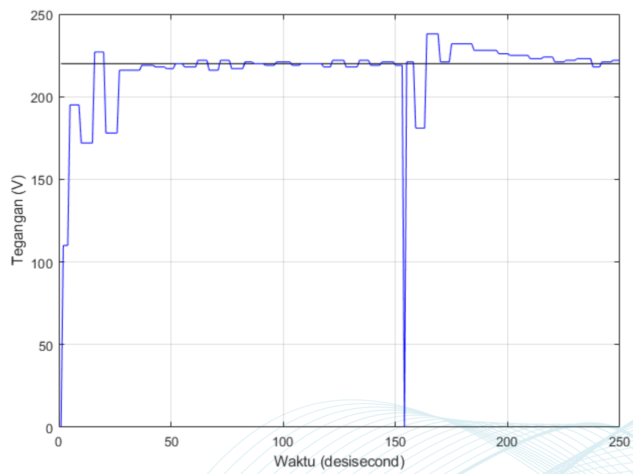


Figure 8: Graph of system reaction with $K_p = 7$, $K_i = 0.5$, $K_d = 0.05$

Figure 8 indicates a system fault, resulting in an incorrect test during the fifth experiment. Based on the five system test results presented in Figures 4-8, the appropriate PID parameter values for mitigating overvoltage are identified as $K_p = 5$, $K_i = 0.3$, and $K_d = 0.01$. The resulting performance metrics include a delay time of 0.35 seconds, a rise time of 0.7 seconds, a peak time of 0 seconds, a maximum overshoot of 0%, a settling time of 8.6 seconds, and a steady-state error of 0%. This test demonstrates the system's efficacy in managing overvoltage occurrences in the low voltage network.

vii. Evaluating the Protection System under Load

Evaluating the protection system under increased load seeks to determine its response to loading conditions, specifically whether there is an impact on voltage, such as overvoltage or failure to achieve the designated setpoint. This test will assess the system's ability to respond to voltage reduction when the voltage exceeds the setpoint under various loads. The PID parameters established in this test are $K_p = 5$, $K_i = 0.3$, and $K_d = 0.01$, which effectively maintain voltage, as illustrated in Figure 8.

viii. Testing with a Lamp Load

This test involves loading the system with a bulb to observe the resultant voltage variations inside the system. Figure 9 demonstrates that the technique effectively safeguards voltage.

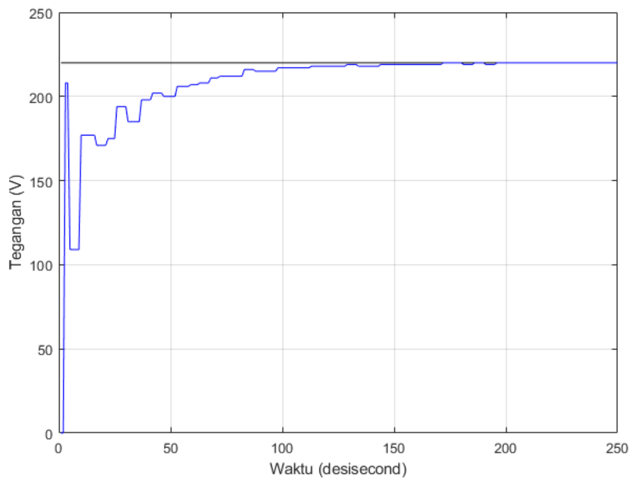


Figure 9: Graph depicting system responsiveness under light load conditions

ix. Testing with Fan Load

Testing with a fan load, as seen in Figure 10, demonstrates that the system reaction effectively stabilizes the voltage with reduced oscillations, remaining within acceptable tolerance levels.

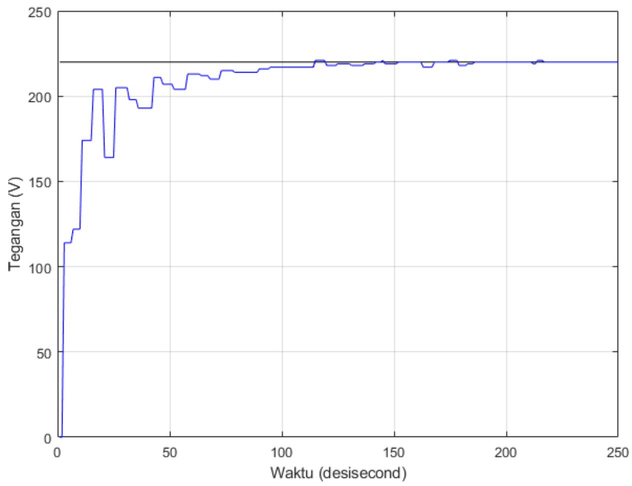


Figure 10: Graph of system response with fan

x. Testing with Iron Load

In the third test, seen in Figure 11, the system is subjected to an iron load. The test findings indicate that the system effectively safeguards the load from damaging overvoltage.

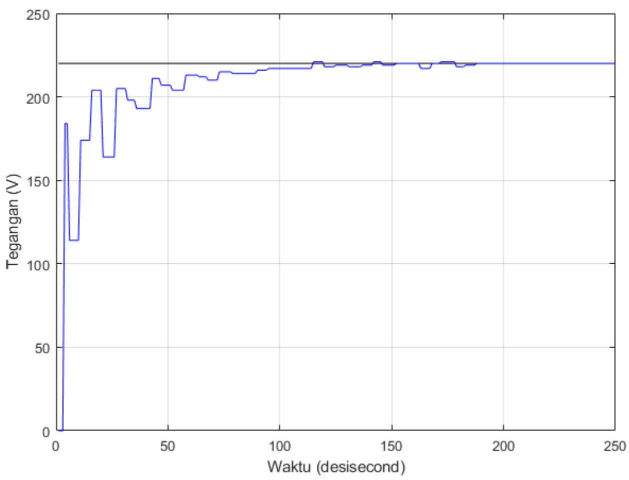


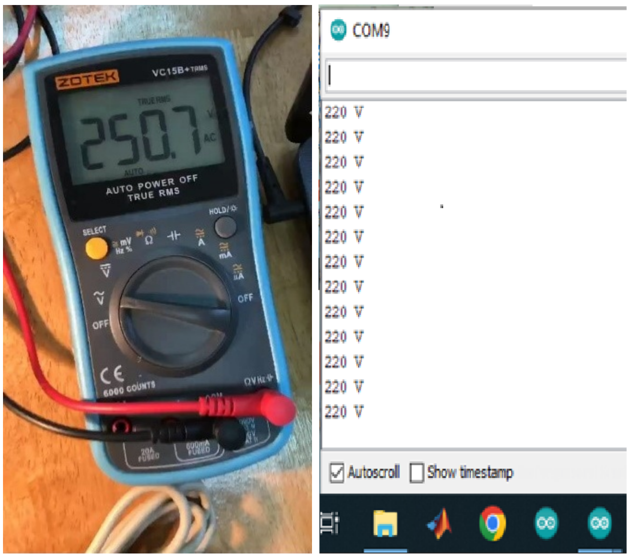
Figure 11: Graph depicting system reaction with iron load

xi. System Testing Outcomes

The voltage readings on this instrument are assessed to compare the input and output values of the system, thereby evaluating its performance in voltage protection. The input voltage fluctuates between 170 and 250 volts. The measurement outcomes are presented in Figure 12 and Table 1.

Figure (a) illustrates the input voltage of the protection device, whereas Figure (b) depicts the output voltage of the protection device, with comprehensive data available in Table 1.

Table 1 indicates that the system testing results demonstrate the tool's capability to safeguard against overvoltage, hence confirming its utility as a voltage



(a) **(b)**

Figure 12: System Testing (a) Input (b) Output

Table 1: Comprehensive Test Outcomes

No	Voltage (V) Input	Voltage (V) Output
1	170	170
2	175	175
3	180	180
4	185	185
5	190	190
6	195	195
7	200	200
8	205	205
9	210	210
10	215	215
11	220	220
12	225	220
13	230	220
14	235	220
15	240	220
16	245	220
17	250	220

protection device when electric voltage abruptly exceeds the reference level.

IV. Conclusion

The suitable PID parameter values for developing this system are $K_p = 5$, $K_i = 0.3$, and $K_d = 0.01$. Acquired values: delay time = 0.35 seconds, rise time = 0.7 seconds, peak time = 0 seconds, maximum overshoot = 0%, settling time = 8.6 seconds, and steady-state error = 0%, indicating that the system successfully mitigated the overvoltage on the low voltage network to the specified setpoint of 220 volts. The test results under varying loads indicate that the designed tool can effectively manage excessive voltage occurrences in the system.

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