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PID Controller Implementation For Temperature Control In Leakage Current Test Chamber 20kv Insulator

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***Keywords*— chamber, leakage current, temperature, insulator, PID controller**

***Abstract*— The Isolator is a device used in electric power systems which is very important to separate between conductor of the electric power systems transmission. Isolators are very influential on environmental conditions such as temperature, humidity and other pollutants. A suitable testing condition is needed to ensure the insulator will do properly. Therefore, it is necessary to test the insulator at a similaractual environment. This test is carried out using a chamber with temperature and humidity settings to determine the characteristics of the leakage current in the insulator. In this paper, a PID Controller is implemented to control the temperature in the chamber. The PID controller is applied in the Arduino R3 microcontroller using a DHT22 sensor and a thermoelectric cooling actuator (TEC12706.) Experimental results show that the PID controller can maintain the chamber temperature at the desired set point with $K_p = 200$, $K_i = 10$, $K_d = 5$. The system can reduce the temperature up to 23.6 °C with a rise time of 198 seconds with a peak time of 218 seconds at a temperature of 24.8 °C. The system can reach at a preset temperature value with a response time of 32 seconds.*

I. INTRODUCTION

Electrical isolators are an important component in electricity to support the safety of electricity operations and implementations. Insulators must consider a specified standard in order to work properly.The insulators must be tested in such a way to determine their performance. One of method used to test the insulator is to determinethe leakage current using a chamber with temperature and humidity settings in order to get a suitable condition environment. Therefore a test room that is controlled with a precise controller is proposed. PID control is implemented in the test room where PID control is a popular feedback controller [1][2].This controller consists of three combined methods, namely proportional, integral, and derivative. The controller uses an Arduino Uno microcontroller with a DHT22 sensor and an actuator in the form of a TEC12706 Peltier. The DHT 22 sensor was chosen because it has high accuracy at-40 – 80°C and humidity measurement of 0-100% RH[3].

In previous research, an on-off control method was applied by Lastoni Wibowo[4].It wasdesigned to a 20 kV isolator leakage test room with temperature and humidity controls.The research work appliedan on-off control method applied in an Arduino Uno Rev.3.The control systems can manipulate the test room to resemble a certain environment conditions to getaccurate test results. In the paper, the temperature setting is carried out at three set points which are a maximum temperature at 33°C with a minimum humidity at 58%, an average temperature at 27°C with an average humidity at 82% and a minimum temperature at 21°C with a maximum humidity at 91%. The experimental results show that the maximum temperature setting with the minimum humidity, the highest temperature is 33.30°C and the lowest humidity is 58.25%. In the average temperature with an average humidity, the measurement results are close to the set point. In this condition, a temperature is 27.25°C with a humidity is 81.60%. In next experimental work, a minimum temperature with maximum humidity, the measurement results are the closest to the set point and the temperature is 25.35°C with humidity is 91.50%.

A Proportional Integral (PI) controller that has been carried out by Bayu Rudianto [5] is used to adjust an automatic expansion valve control of an evaporator. In this study, the performance of the PI control system got a good response at parameter values of K_p=20 and K_i=10. In this parameter configuration, it takes 251 seconds to reach the presettemperature with a lower maximum overshoot value is -2.4˚C. The experimental work using an automatic expansion valve control system showed a faster cooling process. The energy required is more efficient, which is equal to 0.265 kWh. In this study, it is proposed to apply a PID controller as temperature control for a 20kv isolator test chamber using microcontroller Arduino Uno R.3. Peltier 12706 is implemented to the cooling process.

II. BASIC OF THEORY

2.1 20 Kv Leakage Current Test Chamber

An insulator must have good insulation properties at high voltage and low voltage applications. Also, It must have a good performance and high resistance, which is indicated by the amount of leakage current in the insulator. Generally, polymer materials have better dielectric properties compared to ceramic, glass, and porcelain materials. Factors that greatly affect the performance of the insulator are temperature, rain, humidity, ultraviolet light, condensation, and contaminants [6] therefore the leakage current is tested on the insulator. Several records showed that the flashover voltage in wet conditions is smaller than in dry conditions[7]. Research conducted by J.Y.Li et al [3] is testing the characteristics of leakage currents in a single suspension isolator with varying contamination and humidity Leakage current testing on the insulator is carried out in a fog chamber that is a test chamber with adjustable humidity. A schematic diagram of the fog chamber system and a sketch of a single suspension insulator are shown in Fig. 1. The test results show the normal threshold of leakage current is <50 ma. This result is used as a threshold to help give an early warning before pollution causes a flashover that can damage the insulator.. To carry out the leakage current test, a conditional chamber must be set up as shown in Figure 1. It was recorded in [3] that the leakage current test room was designed using the on-off control method. Testing using a chamber with an Arduino R3 microcontroller controller and actuators in the form of a cooler, heater, humidifier, and fan. In the setting of the highest temperature point set 33°C with the lowest set point humidity 58 %, the highest temperature achievement results occurred in the 22[nd] minute with a temperature measurement of 33.30 ° C with a humidity of 58.65%, while the results of achieving the lowest humidity occurred at 23 minutes with a humidity measurement of 58.25% with a temperature of 33.25°C. At the highest temperature setting with the lowest humidity, it is carried out in a duration of 53 minutes.

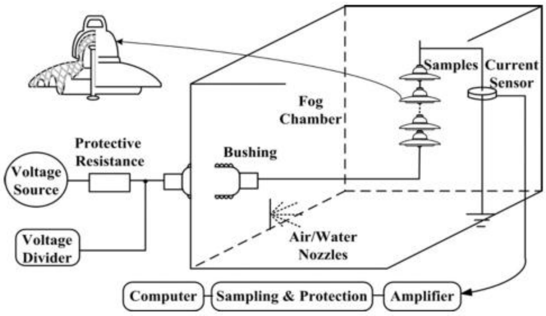

Fig.1: Diagram of the fog chamber system and sketch of single suspension isolator[7]

2.2 Effect of temperature on leakage current

It is common that the isolator design has to have a breakdown voltage higher than its flashover voltage. The dielectric strength and voltage value can be estimated from three basic characteristics of the insulator, i.e. alternating flashover voltage in dry conditions, alternating flashover voltage in wet conditions, and time-voltage characteristics obtained from standard surge voltage [3]. The testing condition for the insulator must follow standard requirement mentioned in Table 1. Table 1 shows the standard conditions of barometric pressure, ambient temperature, and absolute humidity based on the Japanese Industrial Standard (JIS) C3801 and the Japanese Electrotechnical Committee (JEC) standard 106.

Table.1 Japan Industrial Standart [8]

	Value	Unit
Barometer Pressure	760	mmHg
Environment Temperature	20	°C
Absoulte Humidity	11	$Gram/m^3$

Because the flashover voltage is always influenced by thestate of the air, so to be able to compare test results with existing normalization tables, we need formulas that canvchange these results into results in standard conditions. This is needed to be able to find out whether the tested specimen meets the requirements or not. To correct the voltage during testing (V) against airpressure and temperature, a formula is used:

$$V = \delta . Vs \quad (1)$$

Where Vs is flashover voltage of isolator at standard state, V is flashover voltage of isolator at the time of testing, and δ is air correction factor

$$\delta = \frac{b}{760} x \frac{273+20}{273+T} = \frac{0,386b}{273+T} \quad (2)$$

Where T is ambient temperature at the time of testing (°C) and b is air pressure at the time of testing (mmHg). The voltage of the insulator's flashover will get lower with increasing humidity in the air. If Vs is the isolator's flashovervoltage under standard air conditions and humidity of 11 gr/m3, the isolator's flashover voltage at any temperature, pressure and humidity can be determined as follows:

$$V = \frac{\delta . V_s}{k_h} \quad (3)$$

Where kh is the air humidity correction factor. To find out the relationship of the flashover voltage to the leakage current, the formula is used:

$$V = I . R \quad (4)$$

Where I is the current and R is the resistance The relationship between humidity (kh) to the leakage current (I) can be known by entering equation (4) into equation (3) it is obtained:

$$R = \frac{V_s}{I . k_h} \quad (5)$$

In equation (5) it can be seen that for fixed values of Vs and I, the value of kh is inversely proportional to the value of R. While in equation (4) it is seen that for a fixed value of V, the value of R is inversely related to the value of I. So the relationship between kh, R and I are:

$$k_h \uparrow : R \downarrow : I \uparrow$$

note: ↑ means increase / height
↓ means decrease / low

While the relationship between temperature (T) to leakage current (I) can be known by entering equation (1) into equation (4), it is obtained:

$$R = \frac{\delta . V_s}{I} \quad (6)$$

In equation (6) it can be seen that for fixed Vs and I, the value of δ is directly proportional to the value of R. Where as in equation (4) it is seen that for a fixed value of V, the value of R is inversely related to the value of I, So the value of δ is inversely proportional to the value I. So for the relationship of temperature (T) to leakage current (I), according to equation (2) for fixed b, T is inversely proportional to δ, then T is directly proportional to I.[8]

2.3 PID Controller

PID control is one type of controller that is widely used in industrial systems and other general applications[9].Since the controller has a good performance, this system can be combined with other systems [1]. PID control actually consists of three combined methods, namely Proportional, Integral, and Derivative with their respectiveparameters so that they can work properly as shown in Figure 2. These parameters are called constant.

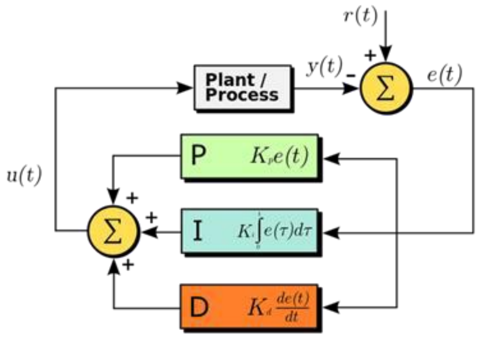

Fig.2: PID Controller Block Diagram

The PID controller in Figure 2 can be written as follows [8]:

$$u(t) = K_p(e)t + K_i \int_0^t e(t)dt + K_d \frac{d}{dt} e(t) \quad (7)$$

where $u(t)$ is system output, K_p is a proportional constant, K_i is an Integrator constant and K_d is a proportional constant[9].

Table.2 PID Controller Kp,Ki,Kd characteristic

Close Loop Response	Rise Time	Over shoot	Settling Time	SS Error
Kp	Increase	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Minor Change	Decrease	Decrease	No Effect

2.4 Arduino Rev.3 Microcontroller

Arduino Uno R3 is a microcontroller board based on ATmega328. It has 14 digital input/output pins (6 pins can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header and a reset button. The featuresare contain in one chip to support the microcontroller[10]. Arduino can be programmed easily because the programming language has been simplified and uses open source systems[11].Pins for analog inputare addressed in A0 - A5. Digital pins from pin is located in pin 2 to pin 13, with a special pin Pulse Width Modulation (PWM) on pins 3,5,6,9,10,11. Arduino can be supplied by 9v to 30v DC using an external power supply as shown in Figure 3 and Figure 4.

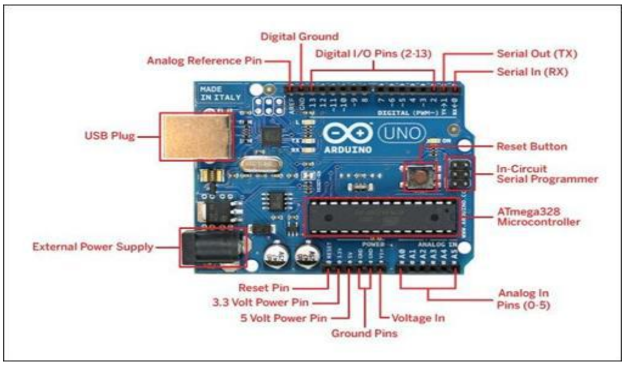

Fig.3: Ardiuino Rev.3Microcontroller

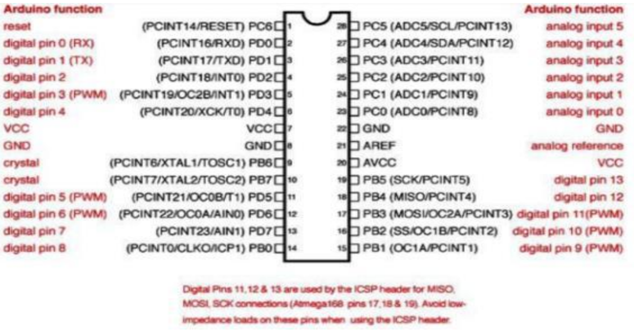

Fig.4: Arduino Rev.3 Microcontroler Pin Mapping[11]

2.5 Thermo Electric Cooler (TEC)

Thermoelectric cooler (TEC) also called aPeltier modules composed of ceramics that contain bismuth telluride. Peltier has two different sides, namely a hot side and a cold side. It can be used for cooling and heating. The principle of Thermo-Electric cooling was first discovered in 1834 by Jean Peltier, so that his invention is often called "Peltier Cooler". When two conductors are connected in electrical contact, electrons will flow from the conductor that has less electrons to the conductor with the more bonded electrons. The most commonly used Thermo-Electric semiconductor material today is Bismuth Telluride (Bi_2Te_3) [12] as shown in Figure 5 and 6. Thermo-Electric is built by two different semiconductors, one type N and the other type P. A Thermo-Electric will produce a maximum temperature difference of 70°C between its hot and cold sides. The efficiency is reduced when the Thermo-Electric become hotter. Thermo-Electric has an efficiency of about 10% - 15%, while the efficiency of conventional models is between 40% - 60%[11]. TEC 12706 performance as shown in table 3

Table.3 TEC 12706 Performance[13]

Hot Side Temperature (ºC)	25ºC	50ºC
Qmax (Watts)	50	57
Delta Tmax (ºC)	66	75
Imax (Amps)	6.4	6.4
Vmax (Volts)	14.4	16.4
Module Resistance (Ohms)	1.98	2.30
Hot Side Temperature (ºC)	25ºC	50ºC

Fig.5: Peltier TEC 12706 [13]

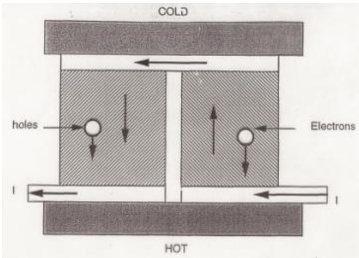

Fig.6: Thermoelectric Schematic Diagram

2.6 DHT 22 Sensor

DHT 22 is a temperature and humidity sensor with 8 bit single chip calibrated output as depicted in Figure 7. The DHT22 consists of a polymer capacitor with a temperature sensing range of -40 - 80°C and a humidity of 0 - 100% RH [3]. The output of the DHT22 or AM2302 is digitally calibrated It employs a proprietary digital signal-gathering technique and moisture sensing technology, ensuring reliability and stability. Its sensing element is connected to a single 8-bit chip. Each sensor of this model is temperature compensated and calibrated in the accurate calibration chamber and the calibration coefficient is stored in the program type in OTP memory, when the sensor detects it will quote the coefficient from memory. Small size & low consumption & long transmission distance (100m) allows the AM2302 or DHT 22 to be adapted in all kinds of demanding applications[14]

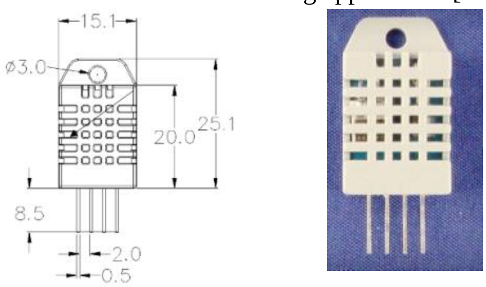

Fig.7: DHT22 Sensor Dimension[15]

Table.4 DHT22 Sensor Technical Data [15]

DHT 22 Technical Data

Power Supply	3.3-6V DC
Output Signal	digital signal via single-bus
Sensing Element	Polymer capacitor
Operating Range	humidity 0-100%RH; temperature -40~80Celsius
Accuracy	humidity +-2%RH(Max +-5%RH); temperature <+-0.5Celsius
Resolution	humidity 0.1%RH; temperature 0.1 Celsius
Repeatibility	humidity +-1%RH; temperature +-0.2Celsius
Humidity Hysteresis	+-0.3%RH
Long Term Stability	+-0.5%RH/year
Sensing Period	Average: 2s
Interchangebility	fully interchangeable
Dimensions	small size 14*18*5.5mm; big size 22*28*5mm

III. METHODS

3.1 Hardware Design

In this reserch work,the PID controller will be programmed in an Arduino Rev.3 microcontroller as shown in Figure 8.Some Thermo electric cooler (TEC) actuatorsare used to reduce the temperature of the test chamber. The TEC is controlled by a Pulse Width Modulation (PWM) signal that is determined according to the PID computation embedded in the microcontroller. Setpoint value is set at 20°C. Firstly, the controller will take a temperature reading on the test chamber room and send it to pin 8 Arduino. PID method will try to control based on the differences between this value to the setpoint or preset value.

Block diagram of the implemented control temperature system for test chamber can be seen in Figure 8. Two TEC units will be installed in the test chamber room for cooling step. The cooling components are driven by a driver as seen in the figure. This driver will amplify the PWM signal coming from Arduino microcontroller to the TEC. As shown in the figure, PWM signal is provide by microcontroller as an output of PID controller. The width or duration depend on the deviation between feedback signal and preset value or setpoint.

Test room or chamber is developed by using a plastic box which has size of 510 x 360 x 290 mm.

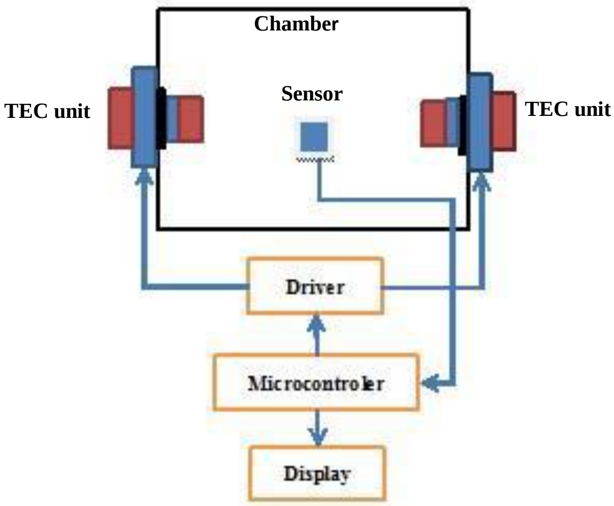

Figure 8. Block Diagram

The PID controller will be implemented using Arduino as mentioned before. The PID algorithm will be programmed using C language. In order to realize the PID controller, a flow chart as shown in Figure 9 is created to determine theprocess for controlling the temperature step by step.

Initially, some variables or constant must be given a value. Then a controlling process will be started at reading a setting point or preset value. The process will be continued by reading the actual temperature value. This value can be taken from a sensor used in this temperature control systems and this value is called feedback signal. As mentioned above, this temperature value is taken from DHT sensor through a dedicated protocol communication.The deviation between setting value and feedback signal value will be used by PID controller to determine the width of PWM signal. This algorithm is applied during controlling process until the temperature is reach to the setting value. The actual temperature value will be displayed on the LCD screen. It can be seen the actual temperature value by looking at the LCD display text. The flow chart which is programmed in Arduino can be seen as shown in Figure 9.

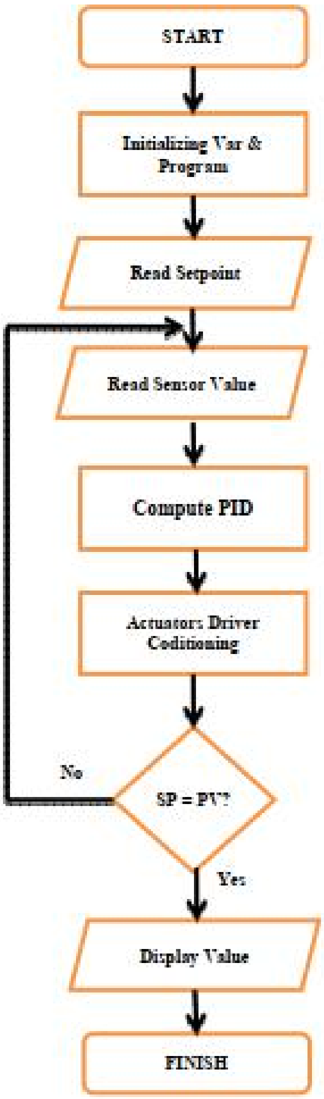

Fig.9: Systems Flow Chart

3.2 Open loop Test

Some experimental work must be done to ensure that the temperature control systems working properly. Open loop thermoelectric test is conducted before the control process is carried out.The first trial is done by giving a 100% PWM duty cycle to the Peltier driver, then the data is recorded in second intervalsas shown in Figure 10.

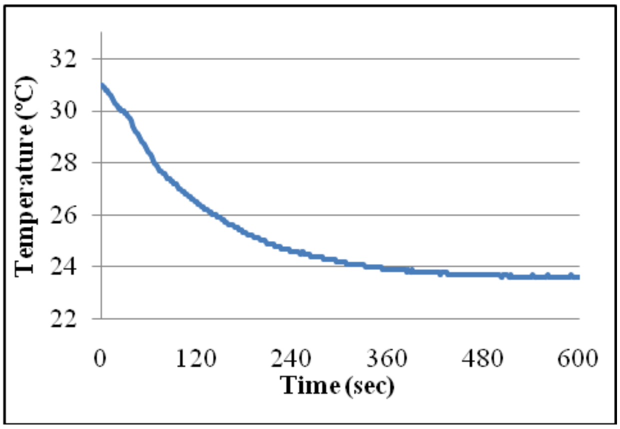

Fig.10: Open Loop Responses

It can be seen that cooling mechanism can be performed by the control system as depicted in Figure 10. It is shown that the system can reduce the temperature from 31°C to 24.6 ° C at 500 seconds. The first experimental work shows that open loop system is working fine.

3.3 PID Controller Test

The PID control process is carried out using a setpoint value of 25°C.ParametersK_p is set to 200,K_i is set to 10 and K_d is set to 5. It is shown in Figure 11 that temperature can be controlled by the control systems. Temperature can be reduced to reach the setting point value. It is also shown that when the temperature is too low, it can be raised up to maintain the predetermine temperature.

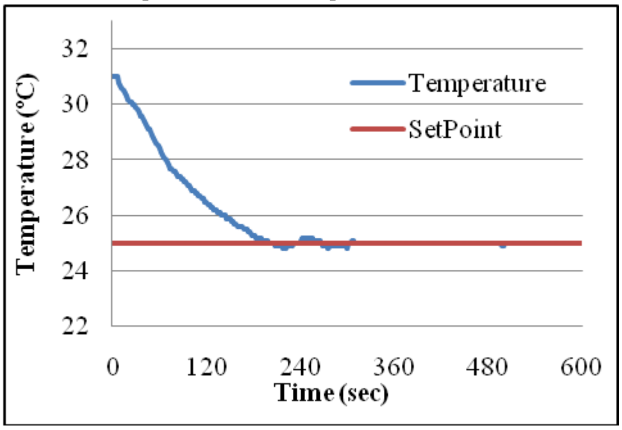

Fig.11: System Responses

Figure 12 show that the set point has been changed from 25ºC to 26ºC.It can be seen the system response. The temperature follows the setpoint with a change in response time of 32 seconds.

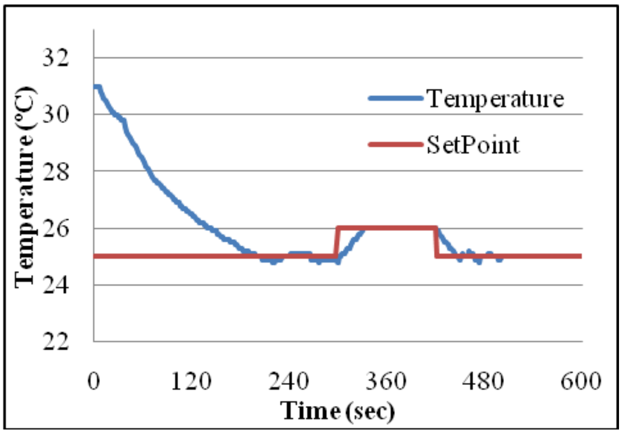

Fig.12: The system response if the setpoint is changed

IV. CONCLUTION

Testing and experimental work for temperature control has been done. The control system will be used in Test chamber as specified in previous section. Based on the experimental results of the implementation of PID control in the 20 kv isolator leakage test room , the temperature can be reduced up to 23.6°C.The rising time is 198 seconds with a peak time of 218 seconds at a temperature of 24.8°C. It is shown also the performance of the temperature control systems. Changing the setpoint of temperature can be tracked by the control systems. The temperature can follow the setpoint with the response time 32 seconds until it reaches steady state.

REFERENCES

[1] 11/2000 © Festo Didactic GmbH & Co., "實驗十六~十九 PID Controller," no. Mv, pp. 1–25, 2000.
[2] M. A. Johnson *et al.*, *PID control: New identification and design methods*. 2005.
[3] AOSONG, "Temperature and Humidity Module, DHT22," *Temp. humidity Modul. AM2302 Prod. Man.*, 2010.
[4] L. Wibowo, A. Syakur, and T. Andromeda, "Design of temperature and humidity control devices in the leakage current test chamber of 20 kV insulator," 2019, doi: 10.1109/ICITACEE.2019.8904318.
[5] B. Rudiyanto, A. Susanto, and Y. Susmiati, "Aplikasi Kontrol PI (Proportional Integral) pada Katup Ekspansi Mesin Pendingin," *Rona Tek. Pertan.*, 2016, doi: 10.17969/rtp.v9i2.5647.
[6] A. Syakur and Hermawan, "Leakage current characteristics at different shed of epoxy resin insulator under rain contaminants," 2015, doi: 10.1109/ICITACEE.2014.7065782.
[7] J. Y. Li, C. X. Sun, and S. A. Sebo, "Humidity and contamination severity impact on the leakage currents of porcelain insulators," *IET Gener. Transm. Distrib.*, 2011, doi: 10.1049/iet-gtd.2009.0559.
[8] A. Aprianto and A. Syakur, "Pengaruh Kelembaban dan Suhu Terhadap Karakteristik Arus Bocor pada Isolator Bahan Resin Epoksi dengan Pengisi Bahan Pasir Silika," no. July 2012, pp. 1–12, 2016.
[9] K. Ogata and J. W. Brewer, "Modern Control Engineering," *J. Dyn. Syst. Meas. Control*, 1971, doi: 10.1115/1.3426465.
[10] Arduino, "Arduino Uno Rev3," *Store.Arduino.Cc*, 2018. .
[11] R. H. Sudhan, M. G. Kumar, A. U. Prakash, S. A. R. Devi, and S. P., "ARDUINO ATMEGA-328 MICROCONTROLLER," *IJIREEICE*, 2015, doi: 10.17148/ijireeice.2015.3406.
[12] G. D. Mahan, "Introduction to thermoelectrics," *APL Mater.*, 2016, doi: 10.1063/1.4954055.
[13] L. Hebei I.T. (Shanghai) Co., "Performance Specifications of TEC1-12706," *Appl. Note*, pp. 2–4, 2010, [Online]. Available: www.hebeiltd.com.cn.
[14] T. Liu, "Digital Humidity and Temperature sensor," *Adfruit*, 2016.
[15] T. Liu, "Digital-Output relative humidity & temperature sensor/module DHT22," *New York Aosong Electron.*, vol. 22, pp. 1–10, 2015, [Online]. Available: https://www.sparkfun.com/datasheets/Sensors/Temperature/DHT22.pdf%0Ahttps://cdn-shop.adafruit.com/datasheets/Digital+humidity+and+temperature+sensor+AM2302.pdf.