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Department of Electrical-Electronic Engineering

DESIGN AND EVALUATION OF A PID-BASED GAS DENSITY MONITORING AND CONTROL SYSTEM FOR SF6 IN GAS-INSULATED SWITCHGEAR

MASTER THESIS

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Turkish Anstract : Kükürt hekzaflorid (SF6) gaz kaçağı, Gaz Yalıtımlı Anahtarlama Teçhizatı (GIS) bulunan yüksek voltajlı elektrik trafo merkezlerinde zorlu bir sorun olarak kabul edilmiştir. SF6 gazı GIS ekipmanı içinde yalıtım sağlamada, çalışma ömrünü ve güvenilirliğini artırmada ve bakım maliyetlerini düşürmede hayati bir rol oynar. Bu yazıda, GIS ekipmanında SF6'nın gaz yoğunluğunu izlemek ve kontrol etmek için bir Orantılı-İntegral-Türev (PID) sistemi öneriyoruz. Sistem, açık kaynaklı Arduino

cihazını kullanan bir LabView ve Arduino simülasyonuna dayanmaktadır. LabView programını, endüstriyel uygulama ile kullanıcı arasında bir arayüz simülasyon programı olarak özellikle kullanıyoruz. Ek olarak, donanım sistemi simülasyonu, açık kaynaklı bir cihaz olarak bir Arduino kartı içerir. Daha sonra, her adım için çıkış yanıtını gözlemleyip kaydederek, simülasyon PID sistemini çalıştırmak için gerekli çalışma koşullarını ve adımları belirleriz. Ardından, çıktı sonuçlarını analiz ediyor ve sistem tasarımının verimliliğini endüstriyel uygulamaların izleme ve kontrol süreçleri açısından değerlendiriyoruz.

Anahtar Kelimeler: Kükürt hekzaflorür (SF6), Gaz İzoleli Anahtarlama Teçhizatı (GIS), Oransal-İntegral-Türev (PID), LabView, Arduino.

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DECLARATION

     I hereby declare that in the preparation of this thesis, scientific and ethical rules have been followed, the works of other persons have been referenced in accordance with the scientific norms if used, and there is no falsification in the user data, any part of the thesis has not been submitted to this university or any other university as another thesis.

Salah Hasan Ali AL-RUBAYIE

/   / 2023

SUMMARY

Sulfur hexafluoride (SF6) gas leakage has been considered a challenging problem in high-voltage electrical substations with Gas-Insulated Switchgear (GIS). SF6 gas plays a vital role in providing insulation inside GIS equipment, increasing its operation lifetime and dependability, and reducing maintenance costs. In this article, we propose a Proportional-Integral-Derivative (PID) system for monitoring and controlling the gas density of SF6 in GIS equipment. The system is based on a LabView and Arduino simulation, utilizing the open-source Arduino device. We specifically exploit the LabView program as an interface simulation program between the industrial application and the user. Additionally, the hardware system simulation incorporates an Arduino card as an open-source device. We then determine the operating conditions and steps required to run the simulation PID system, observing and recording the output response for each step. Subsequently, we analyze the output results and evaluate the system design's efficiency in terms of industrial applications' monitoring and control processes.

Keywords: Sulfur hexafluoride (SF6), Gas-Insulated Switchgear (GIS), Proportional-Integral-Derivative (PID), LabView, and Arduino.

ÖZET

Kükürt hekzaflorid (SF6) gaz kaçağı, Gaz Yalıtımlı Anahtarlama Teçhizatı (GIS) bulunan yüksek voltajlı elektrik trafo merkezlerinde zorlu bir sorun olarak kabul edilmiştir. SF6 gazı GIS ekipmanı içinde yalıtım sağlamada, çalışma ömrünü ve güvenilirliğini artırmada ve bakım maliyetlerini düşürmede hayati bir rol oynar. Bu yazıda, GIS ekipmanında SF6'nın gaz yoğunluğunu izlemek ve kontrol etmek için bir Orantılı-İntegral-Türev (PID) sistemi öneriyoruz. Sistem, açık kaynaklı Arduino cihazını kullanan bir LabView ve Arduino simülasyonuna dayanmaktadır. LabView programını, endüstriyel uygulama ile kullanıcı arasında bir arayüz simülasyon programı olarak özellikle kullanıyoruz. Ek olarak, donanım sistemi simülasyonu, açık kaynaklı bir cihaz olarak bir Arduino kartı içerir. Daha sonra, her adım için çıkış yanıtını gözlemleyip kaydederek, simülasyon PID sistemini çalıştırmak için gerekli çalışma koşullarını ve adımları belirleriz. Ardından, çıktı sonuçlarını analiz ediyor ve sistem tasarımının verimliliğini endüstriyel uygulamaların izleme ve kontrol süreçleri açısından değerlendiriyoruz.

AnahtarKelimeler: Kükürt hekzaflorür (SF6), Gaz İzoleli Anahtarlama Teçhizatı (GIS), Oransal-İntegral-Türev (PID), LabView, Arduino.

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ABBREDIVATIONS

AIS	:	Air insulated Switchgear
D	:	Density of gas
DSIF	:	Density sensor interface
GIS	:	Gas Insulated Switchgear
GMS	:	Gas Monitoring System
GSM	:	Global System of Mobile communication
Kd	:	Derivative gain
Ki	:	Integral gain
Kp	:	Proportional gain
Ku	:	Ultimate gain
LABVIEW	:	Laboratory Virtual Engineering Workbench
LIFA	:	LabView Interface for Arduino function
LCC	:	Local control cabinet
LPG	:	Liquefied Petroleum Gas
m	:	mass
M	:	Molecular weight
N	:	no. of moles
P	:	Pressure
PID	:	Proportional-integral-derivative
R	:	Ideal gas factor
SF6	:	Sulfur hexafluoride
T	:	Absolute Temperature
Td	:	Derivative Time
Ti	:	Integral Time
Tu	:	Ultimate Time
V	:	Volume
w$_n$	:	Natural (normal) frequency

θ	**:**	Damping angle
ζ	**:**	Damping ratio

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PREFACE

It is my pleasure here to express the due thanks to my professors, Mahmoud H. *K. AL-Dababsa* and Prof. Dr. Izzet GUMUS , for their continual support during the entire time taken to accomplish this thesis. I would also like to express my appreciation and thanks to all the remarkable professors, and all the staff of Istanbul Gelişim University who accompanied us during our academic journey. I also wish to thank my family for their patience and support throughout my study period.

I would like to dedicate my thesis to my dear parents and my beloved wife and children, wishing that one day they have the apportunity to read it and share with me their memories with joy and happiness.

CHAPTER ONE

INTRODUCTION

1.1. Background about GIS High Voltage substation

Gas Insulated Switchgear (GIS) units are significant conducting structures in a sealed environment. Sulfur hexafluoride (SF6), a dielectric gas, insulates them. Air-insulated Switchgear (AIS) units typically have outdoor locations that use ambient air as the gas medium. The electrical parts are contained in a metal frame with SF6 gas in a GIS substation. High-voltage systems of the 1920s used metal-enclosed substations with oil as the insulating medium. Studies concentrated on other gases, and a Freon-based GIS first appeared in the 1930s . Over the following several decades, the industry adopted the usage of SF6 due to breakthroughs in industrial processes, chemistry, and physics. As the 20th century ended, SF6 gas became the primary GIS insulator for arc extinguishing. A whole substation can be smaller overall because clearances between components (such as circuit breakers, bus bars, and isolators) are smaller with a higher dielectric strength than air. An AIS facility is roughly ten times larger than a GIS facility. Thousands of indoor and outdoor GIS have been placed globally since the introduction of SF6 to the industry. The present generation of GIS devices was made possible by the research and the ongoing development of the first system types by Asea Brown Boveri (ABB) Italian company. GIS can be very cost-effective due to its lightweight, long lifespan, low running expenses, and modular, space-saving design. Future GIS Technology Innovations are constantly changing and developing. Enhancing GIS design, production, testing, and operating technologies and best practices are becoming increasingly important. According to the Toshiba website, Meidensha and Toshiba have been working together to develop GIS using gases of natural origin (WG23 et al,2000). Due to the increased desire for a carbon-neutral footprint, the gas will not contain any SF6 gas. By March 2022, the two businesses want to confirm performance and testing.

1.2. Literature Review

There are many researches work in the field of monitoring and controlling SF6 gas leakage in GIS substations in the entire world and which presents different methods and theories such as:

- The researchers Geeta Loshali , Rohit Basera, Lalit Darmwal and Sachin Varma from Amrapali Institute of Technology and Sciences, Haldwani, Nainital, (U.K.), India presents a reseach with a title ," Design & Implementation of LPG Gas Detector using GSM Module " to handle the serious problem of gas leakages in household and other areas .The goal of the project is to build a system that can identify gas leaks and notify users via alarm along with status display. The system offers the design strategy for both the hardware and software. It made use of numerous hardware components, including a solenoid valve, buzzer, microprocessor, and gas sensor. In essence, a solenoid valve became a crucial control component for turning off the cooker's gas flow source. The technology functions similar to a first aid kit, instantly alerting individuals nearby to the need for assistance through both an audio warning and a visual display. As a result of the alarm ceasing to beep once when the concentration for the gas in the environment after a leak falls below the set point and the valve opening again for operations, the system is clever in that it does not cause annoyance by continuously sounding the alert. This will reduce financial losses brought on by explosions brought on by gas leaks and increase life safety. In particular, a gas sensor with excellent sensitivity for butane (C_4H_{10}) and propane (C_3H_8) has been deployed. The GSM (Global System of Mobile communication) unit of the gas leak detection system sends SMS alerts as a warning. LPG was released into the air near the sensor to conduct testing. It is being detected by the gas detection and response equipment. The outcomes of tests done on the device for gas concentration in the air around the sensor at various times and days. A mechanism that can identify these leaks and cut off the burner's gas supply from the gas cylinder was created. It was found that response time in the LPG device reduced when the distance to the gas source grew and vice versa whenever the LPG system was tested by positioning it at various distances to the gas source. The

reference voltage stayed constant throughout time, however the sensitivity of the gas sensor changed with temperature (Loshali et al,2017).

- Another researchers, Aborisadeb,D.O and Adewuyi P.A-2014,from department of Department of Electronic/Electrical Engineering Ladoke Akintola University of Technology, Nigeria and Department of Mechatronics Engineering, Bells University of Technology, Nigeria presents a research of the title "Evaluation of PID Tuning Methods on Direct Gas-Fired Oven" using PID control system to get control process of oven temperature. The objective of the study was improve the dynamic

- performance of the system output like settling time, rise time and maximum overshoot at three different set points. The methodology used to reach stability and good transient performance of the PID control system used an auto-tuning methods. The overall model of gas-fired oven temperature control system with PID controllers is implemented using MATLAB/Simulink. The Ziegler-Nichols closed loop, Good Gain and Skogestad's are the PID tuning methods implemented in this study to control the output temperature of the gas-fired oven system. The PID tuning methods are done using three set points of temperature and test the system performance. The system output results are compared, and analysed based on their rise time, maximum overshoot and settling time. The results showed that the performance of Skogestad's tuning method at different temperature set point is superior to Ziegler-Nichols closed loop and Good Gain PID tuning method (Aborisadeet al,2014).

1.3 Structure of a GIS Substation

GIS high voltage substation is one of the basic and important unit of electric energy transferring network where it step-down the incoming high voltage level to lowest voltage level. All GIS substation's element work together in order to complete the operation function.

1- 33/11.5kV,31.5MV High Power Transformer

Transformers are used throughout the electrical grid Step voltages up and down for transmission, distribution, and consumption Located at power stations, substations, along distribution feeders, and at industrial customers. See Figure 1.Below.

Figure 1. High Power Transformer

2- Enclosures of GIS switchgear

Today, enclosures are generally cast or welded aluminum. Steel is also sometimes used. Steel enclosures are painted both inside and out to prevent rusting. Aluminum enclosures do not require paint but, may be painted for easier cleaning and appearance.

GIS switchgear consists of two types:

    a) 33kV GIS Switchgear

    b) 11kV GIS Switchgear

3- Monitoring and controlling system

4- DC110V Battery & charger

5- The distribution panel and inverter

6- Station distribution panel for LVAC

7- Fire Alarm and Detection System

8- 11/0.4kv Auxiliary transformer.

1.4. GAS Monitoring System

The system consists of the following parts:-

1.4.1. Gas Monitoring Devices

For each phase, a separate gas zone is monitored independently for gas density. Density sensors continuously monitor the amount of gas in each zone and, when it exceeds predetermined limits, they sound the accompanying alarms. Through comparison to the density of an identical gas in a sealed container region within the sensor, the density sensor keeps track of the actual density of the insulating gas in a gas zone (Barnett et al ,2010).The DSIF, or density sensor interface mounted in the GIS bay's local control cabinet (LCC) receives the values from the sensors in a constant flow of unique bursts of current, whose frequency is only dependent on the gas density being watched. The sensors' required supply voltage is provided by the DSIF, a computer system that handles data. The DSIF determines related gas density value for each zone based on the measured frequency.

For each sensor separately, the DSIF may configured with the density warnings and density alert limits. The device continually compares the real values to the permitted values and broadcasts a Signal when any density value drops below any of the limitations(Yang et al ,2021).
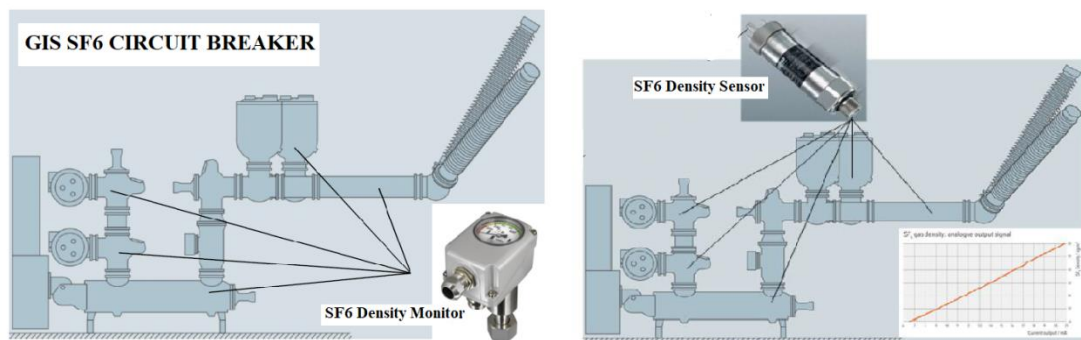
Figure 2. SF6 gas densities Sensor and Monitor

1.4.2. The SF6 gas Leakage Expected Areas

1. Leak in the interior bus section.

Figure 3. Point of SF6 gas leakage

2. Outdoor bus section pin hook leak
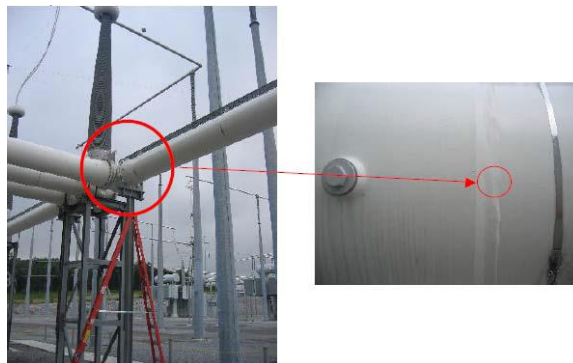
Figure 4. Point of SF6 gas leakage

3. Maury SF6 /Air Bushing Leak

In December 2004, the Maury GIS was placed into operation. A gas leak was discovered in an SF6/Air bushing in July 2006.The bushing was replaced in October 2006 after examination of trends from the GMS revealed a low rate of leaking, and it was subsequently shipped back to the maker for inspection and testing. Metal flanges are used to close and seal the composite hollow bushing. A "Leak meter 200" leakage test revealed significant leakage (more than 1000 ppm) in the region where the fiberglass tube and the top iron flange meet. Leak detection spray could also find the leak (Figure 5). The tube's top flange was removed, chopped into rings that were 20 mm wide, and then placed the dye bath that was from 2 to 3 mm deep. After some

time, a dye penetration was seen in all rings. The first finding was supported by the alignment of the leaking point and all rings' penetration channels (Franks J.et al,2022).

Figure 5. Leak detection utilizing detecting spray.

1.5. GIS High Voltage Substation Problems

Sulfur hexafluoride (SF6) gas plays an important role in the electrical power system, not only a role of insulation and arc suppression, but also it supports the information carrier of the equipment status. GIS high voltage electrical substations use a SF6 gas in arc extinguishing inside the electrical equipment, that arc which results from continuous switching of electrical power. Therefore, any reduction of gas amount results from gas leakage through the GIS equipment or different in gas density will make a serious insulation problem may led to an explosion of these equipment. Furthermore, without existing SF6 gas between high voltage switching poles elements make it's contact surfaces which responsible for connecting and disconnecting the electric current vulnerable to damage and rapid corrosion due to instantaneous discharge electrical arc which appears as a spark of high and instantaneous temperature that leads to melting of those surfaces and thus the surface area of the connection decreases and cause to creating irregular areas on those surfaces that weaken the overall conductivity property of the current .Therefore, in his study we take into account these problems by designing a monitoring and controlling system with a PID principle in order to study the process parameter and system's response behaviour , record and analyse the results for the future studies and improvement.

1.6. Motivation

The motivations of this thesis can be highlighted as follows:

• The SF6 gas plays a vital role in the electrical power system, not only in insulation and arc suppression but also supports the information carrier of the equipment status. GIS high voltage electrical substations use an SF6 gas in arc extinguishing inside the electrical equipment, that arc which results from continuous switching of electrical power. Therefore, any reduction of the gas amount resulting from gas leakage through the GIS equipment or difference in gas density will create a severe insulation problem that may lead to an explosion of this equipment. Hence, we need to sustain the continuity of GIS substation electrical power energy by using a PID monitoring and controlling design to sustain the required safety gas density inside the GIS equipment and also to ensure an automatic SF6 gas filling from the gas conserver tank without shutdown the substation and compensate the leakage gas amount to satisfy the required safety gas density.

• Without existing SF6 gas between high voltage switching poles, elements make its contact surfaces which are responsible for connecting and disconnecting the electric current, vulnerable to damage and rapid corrosion due to instantaneous discharge electrical arc, which appears as a spark of high and instantaneous temperature that leads to melting of those surfaces and thus the surface area of the connection decreases and cause to creating irregular areas on those surfaces that weaken the overall conductivity property of the current. Therefore, in this study, we consider these problems by designing a monitoring and controlling system with a PID principle to study the process parameter and system response behavior and record and analyze the results for future studies and improvement.

1.7. Research Objectives

The present thesis aims at:

1. Design a PID monitoring and control system for SF6 gas leakage case by depending a gas density as a main process variable parameter.

2. Use LabView program as an interface simulation program between industrial application and the user.

3. The hardware system simulation also uses Arduino card as an open-source device and extra elements like sensors, relays, solenoid valve and Alarm buzzer.

4. Determine the operation conditions and steps of running the simulation PID system and observe the output response for each step.

5. Analyze the output results and evaluate the system's design performance efficiency for monitoring and control processes for industrial application.

1.8. Thesis Structure and Organization

The chapters of the thesis are organized as follows:

Chapter 1: This chapter presents a background about GIS substations and a literature survey for GIS monitoring and controlling researches by showing the research tackled and authors' contribution was acknowledged, and the research void was noted the same topic.

Chapter 2: This chapter presents an overview of a PID control system, PID system types, PID controller algorithm types and important system properties.

Chapter 3: This chapter gives the detailed for SF6 gas monitoring and controlling system's requirements.

Chapter 4: This chapter concludes the proposed work for SF6 gas monitoring and controlling system design, implementation and analysis to gives direction to future work.

Chapter 5: This chapter shows the conclusion, recommendation and future work.

CHAPTER TWO

OVERVIEW OF PID SYSTEM

2.1. Control system Principle

2.1.1 Definition of Control System

A dynamic system is described as a group of interdependent parts that can work together to achieve a certain goal and its behavior can described by a group of differential equations or difference equations. Normally, the system creates a response (output) in response to an excitation (input). The system variables are to blame for its actions. As seen in Figure 6, these can be divided into four groups:-

1-Input variables: The system is stimulated by the inputs, which are frequently human-operated.

2- Disturbance variables: Which are inputs to the system that operator has no control over. They typically result from the system's surroundings or internal parts. They typically result in a departure from the predicted behaviour of the system.

3- Output variables: Measurable responses of the system to both the input plus disturbance variables combined.

 4- State variables: These internal variables explain the system's behaviour and detail how the output responds to a confluence of disturbance and input components (Pay M. et al ,2011).
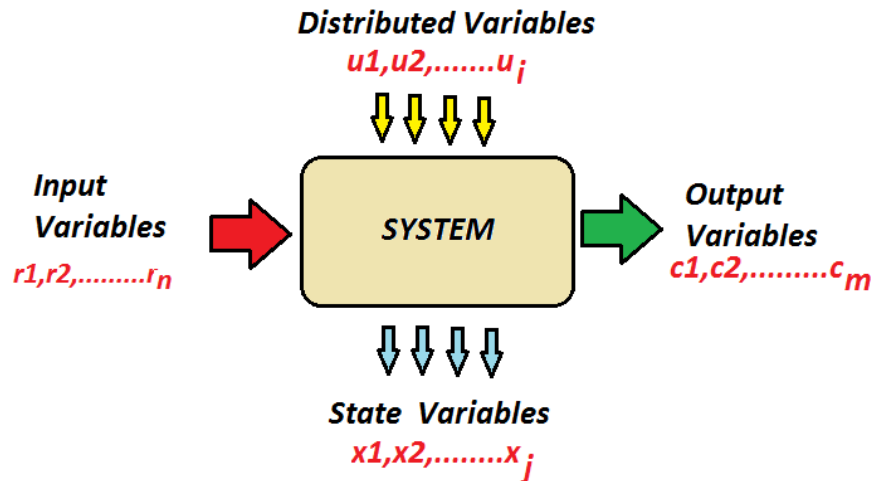
Figure 6 . The system's variables

2.1.2. Types of Control Systems

Having adequate inputs is necessary for producing the intended output response. However, acceptable inputs are not always compatible with the operator-controlled input system. In order to provide the proper system inputs for the desired response, To modify (or reshape) the operator's control input, a controller is added.

1- System of Open-Loop Control

The most basic form of a control system is shown in Figure 7 as a controller with the system controlling combined without feedback.
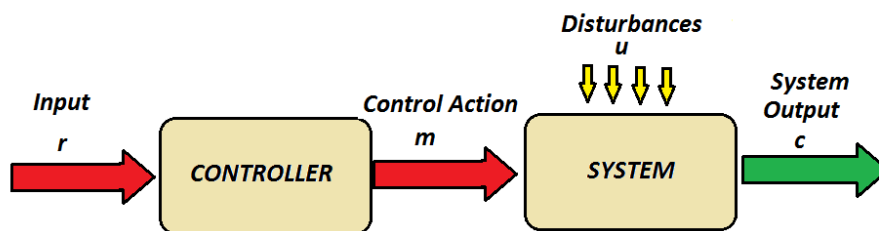
Figure 7 . A common open-loop control scheme.

We call this open-loop controlling. Such a plan will alter user inputs, but it depends on the system's time-invariant characteristics. Such a plan is frequently unworkable for systems other than the simplest ones because it also disregards the impacts of outside factors.

2- System of Closed-Loop Control

The performance of the closed loop system is made less responsive to changes in the plant by implementing negative feedback. A thorough discussion On the effect on system sensitivity of negative feedback can be found in any decent work on systems theory. Additionally, given a closed system with good design, negative feedback typically has high disturbance rejection properties. Fundamentally, later, more thorough discussion of the system's behaviour will be shaped by a suitable controller. A controller providing negative feedback is shown in Figure 8.
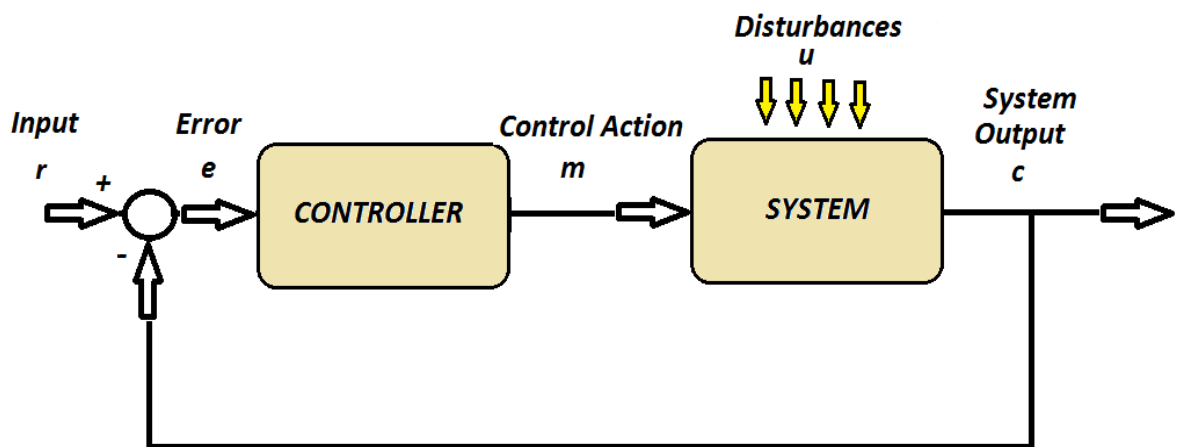
Figure 8 . A Common closed-loop control system

2.2 Laplace Transform

Differential equations can be applied to symbolize a linear system's mathematical description. The degree of the mathematical representation's complexity is often determined by the complexity of the system. An alternate representation is provided by the Laplace transform. It is based on converting integrating the equations from a time domain to another domain like S-domain, which simplifies analysis. It is provided by

$$\mathcal{L}[x(t)] = X(s) = \int_{-\infty}^{\infty} x(t)\, e^{-st} dt \tag{1}$$

while

$$s = \sigma + j\, w \tag{2}$$

The bidirectional Laplace transformation will integrating across full time in both directions positive and negative, is this particular form. However, as dynamic systems are typically thought to be inactive before stimuli, it is customary to modify the integration limits to produce the solitary-sided Laplace transform, which used in the following:

$$\mathcal{L}[x(t)] = X(s) = \int_{0}^{\infty} x(t)\, e^{-st} dt \tag{3}$$

The change from x to X symbols is to denote in the Laplace domain, a function is merely a matter of tradition and does not signify any new system properties . Differential equations are easier to handle when transformed to the Laplace domain for algebraic expressions. The key two elements that make this possible are:

$$\mathcal{L}\left[\frac{d\, x(t)}{dt}\right] = S\, X(s) - x(0) \tag{4}$$

Also

$$\mathcal{L}\left[\int_{0}^{\infty} x(t)\, dt\right] = \frac{1}{s}\, X(s) \tag{5}$$

Once more, this is typically rearranged to produce a system transfer function of the ratio output to input parameters:

$$G(s) = \frac{Y(s)}{X(s)} \qquad (6)$$

Similar to this, A(s) can be used to define a controller's Laplace domain representation. Figure 9 shows a series controller's physical layout.
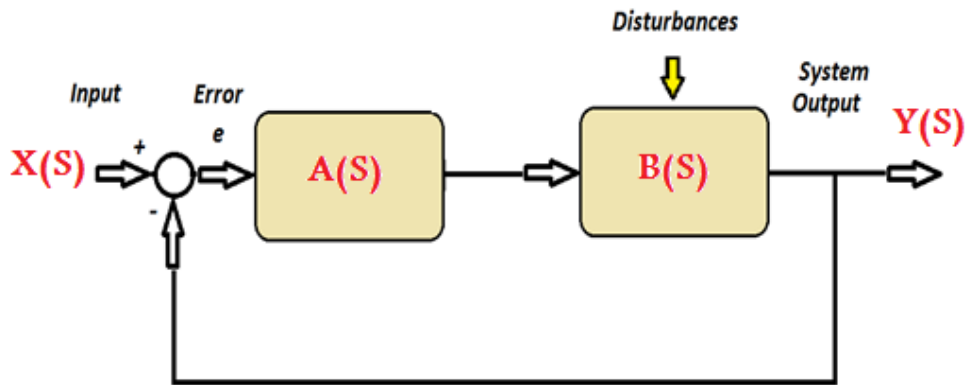
Figure 9. Negative feedback in a Laplace domain with an additional controller

For this system, transfer function is:

$$G(s) = \frac{Y(s)}{X(s)} = \frac{A(s).B(s)}{1 + A(s).B(s)} \qquad (7)$$

Clearly, by modifying the transfer Function A (s) to meet the needs, the controlled system's characteristics can be changed. The linear system's impulse Laplace transform is represented by B(s). To produce the result .The convolution operator must be applied in the time domain for any random input.

$$y(t) = \int_0^\infty x(\tau)\, b(t\text{-}\tau)\, e^{-st} d\tau \qquad (8)$$

This operation is represented by the symbol x (t) * b (t). Convolution of the time domain is identical to multiplication for the Laplace domain and reversed, which is a valuable property in a Laplace domain representation.

$\mathcal{L}$ [x (t) * b (t)] = X(s). B(s) = Y (s) $\hspace{3cm}$ (9)

$\hspace{1cm}$ Also

$\mathcal{L}$ [x (t). b (t)] = X(s) * B(s) $\hspace{3cm}$ (10)

This makes figuring out the output given a certain input much simpler. A collection of common inputs and associated Laplace domain representations are shown in Table 1.

Table 1. Table of Laplace transforms

$x(t)$	$X(s)$
Unit impulse, $\delta\,(t)$	1
Unit step, $u\,(t)$	$\frac{1}{s}$
$t \cdot u\,(t)$	$\frac{1}{s^2}$
$t^n \cdot u\,(t)$	$\frac{n!}{s^{n+1}}$
$e^{-at} \cdot u\,(t)$	$\frac{1}{s+a}$
$\sin\,(\omega t) \cdot u\,(t)$	$\frac{\omega}{s^2+\omega^2}$
$\cos\,(\omega t) \cdot u\,(t)$	$\frac{s}{s^2+\omega^2}$

2.2.1. System Poles and Zeros

Understanding the system poles and zeros is crucial for the analysis of system behaviour. Formally, the s Laplace parameter values represent the poles.

$\hspace{0.5cm}$ G(s) = ∞ $\hspace{6cm}$ (11)

In a similar manner, a system's zeros are s values such that

$\hspace{0.5cm}$ G(s) = 0 $\hspace{6cm}$ (12)

These are generally shown using an s-plane diagram, which shows the complex variable's poles and zeros and represents them(Hauksdóttir ET AL ,2018).

2.2.2. Important System Properties

Three key system properties must be taken into account by a control engineer when creating a controller for a system:

1- Stability.

2- The behaviours of transition .

3- Performance for steady state errors.

The map of pole and -zero sheds light on each of the three system characteristics. For more information, Readers are directed to any reliable text on control engineering.

2.2.3 Stability

A stable system can be define as:

Dynamic system with bounded input and bounded reaction the phrase "absolute stability" is frequently used to refer to this. The complicated s-plane's left side must include all of the poles for such a system. However, relative stability different levels of stability is a real phenomenon. If a small, brief transient input disturbance occurs, a stable system's output will return to its initial value. The system's relative stability, or the transitory behaviour, is what's utilized to describe how it does this(Ang K.H et al,2005).

2.2.4 Transient Behaviour

When building a control system, it is imperative to take the system's transitory reaction into consideration. For an example of a lift where comfort and tolerance must be compromised. if the elevator go too fast, the occupants will faces severe, uncomfortable forces. An opposite is also true: It will require a long time for them to arrive at the floor if the elevator goes too slowly, which will annoy the users. By using specific input test signals, like steps, escalators and impulses, the control engineer could gain greater insight into transitory behaviour that is generally based on the output.

1- Overshoot per cent and settling time.

2- Oscillation behavior.

3- fast of reaction response.

Suppose Equation 13 provides the common second order system shown below, where w_n the system's natural (normal) frequency and ζ is its damping ratio.

$$\frac{w_n{}^2}{S^2 + 2\zeta w_n\, S + w_n{}^2} \qquad (13)$$

In Figure 10, a Pole-Zero plans is what this translates to.
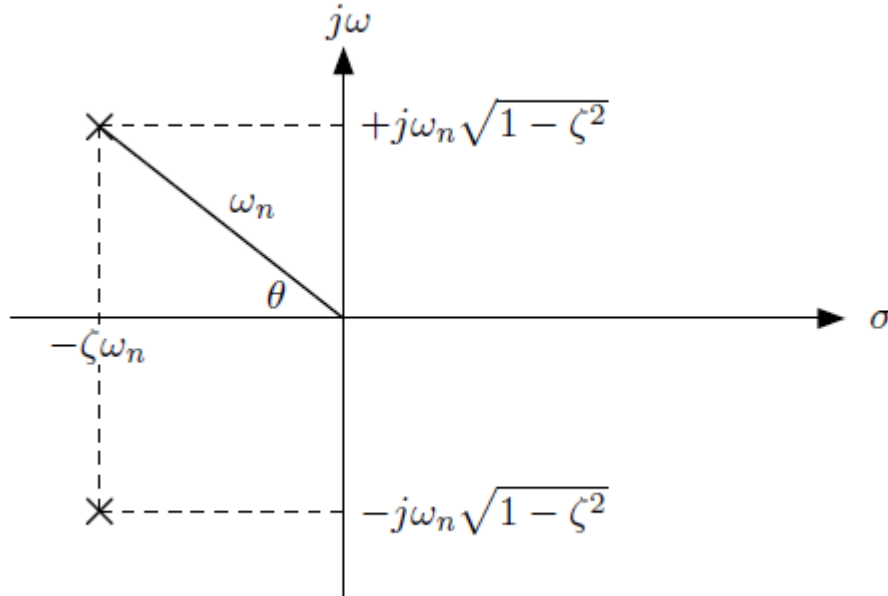
Figure 10. A second order the under damped system's pole plot.

Modified from, The formula for the damping angle, θ, is :

$$\zeta = \cos\theta \qquad (14)$$

1- Percentage overshoots time of settling

The required amount of time of the system to settle to approximately 98% of the total settled output value is known as the time required for settling, or Ts.

$$Ts \approx \frac{4}{\zeta wn} \qquad (15)$$

The maximum of what is referred to as the percentage overshoot, or %O.S. Peak of the curve of response as measured in relation to the value at the end of the steady state. Equation 16 can be used to compute it.

% O.S

$$= [\exp\{^{-}(\frac{\zeta\pi}{\sqrt{1-\zeta^2}})\}]*100 \qquad (16)$$

While the % OS is only a function of, settling depends on both the damping ratio ζ and the normal frequency of the poles, wn .The link between pole locations and fluctuations is depicted in Figure 11.

a) settling times are constant.
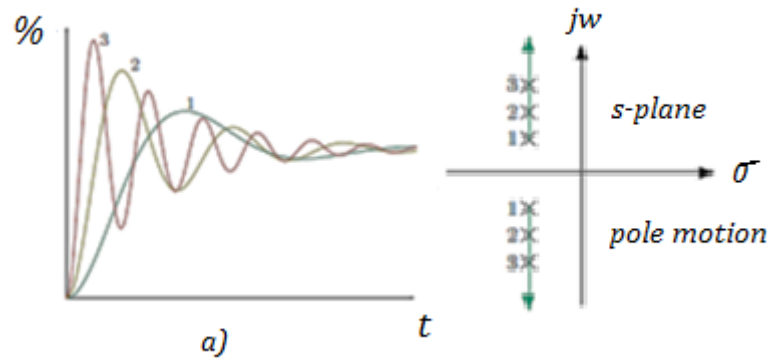
Figure 11. Pole migration on a step responses- outcome state-a.

b) Gives constant natural frequency .
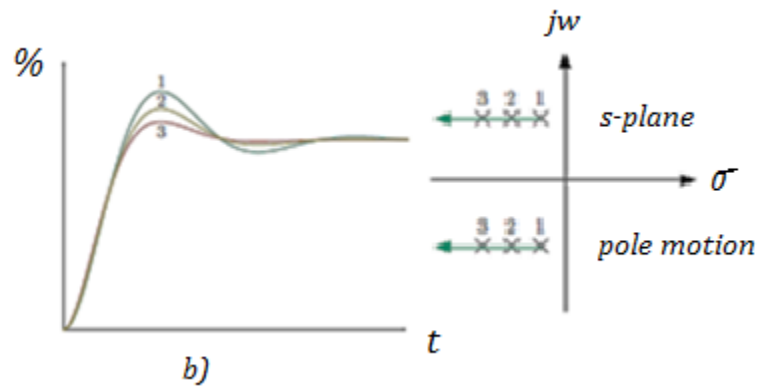
Figure 12. Pole migration on a step responses- outcome state-b.

c) provides overshoot and constant damping.
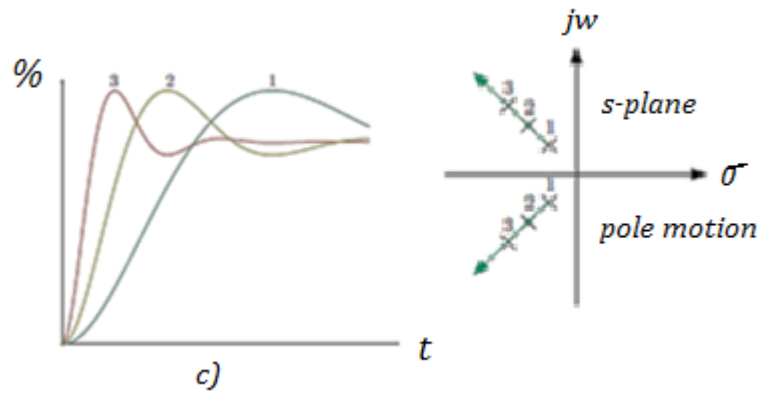
Figure 13. Pole migration on a step responses- outcome state-c.

2-Oscillatory Behaviour

Clearly, oscillatory behaviour in the context of damping with frequency have a strong association with complicated pole pair positions.

3- Steady State Error

Once all transients have gone, the remaining difference between the desired and the realized is what is referred to as the steady state error output levels. Using the lift analogy from earlier, After the doors are closed, if there exists a step upward or downward between the elevator floor and the building's first floor, the elevator controller's steady state issue is to blame. Analytically, the performance of the open loop transfer function in the absence of a dynamic controller specifies a steady-state error of a closed loop. The amount of only pure integrators within the system type, open loop plant, determines this. If an input signal be step, ramp, or a higher order will affect the mistakes. It is possible to collect them in a tabular fashion, as shown in Figure 14. There is a constant gain value(K).

Table 2. Constant state error relative to the gain K

	Step input $r\left(t\right)=1$	Ramp input $r\left(t\right)=t$	Parabola input $r\left(t\right)=\frac{1}{2}t^2$
Type 0 system	$\frac{1}{1+K}$	∞	∞
Type 1 system	0	$\frac{1}{K}$	∞
Type 2 system	0	0	$\frac{1}{K}$
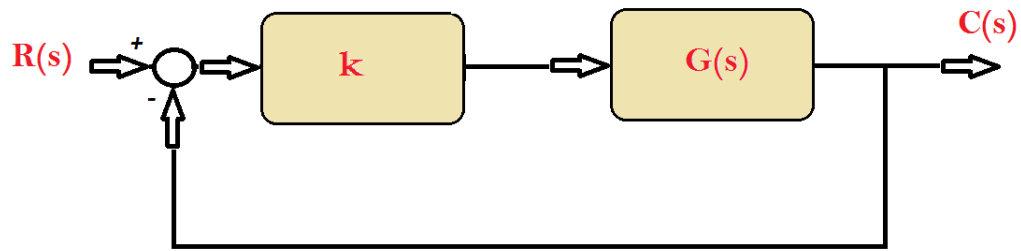
Figure 14 . The configuration of the negative feedback control.

When implementing a suitable controlling mechanism, These errors might fixed and temporary behaviour can be enhanced. The PID Approach is a typical control policies.

2.3. P-I-D Controller Transfer Function Types

We can classify the PID controller into three controlling mode according to how many controlling mode entering the design controlling algorithm share to produce the required output response of the controller(Sahoo,et al,2013).

2.3.1. Single mode controller Transfer Function

These modes are:-

It almost known as P-Controller .It basically contains only a P-controller where the effective parameter here is proportional constant (K_P) So, the transfer function of the system will be :-

$$Gc = K_P = \frac{u}{E}$$

2.3.2. Double mode controller Transfer Function

It basically contains P-controller where the effective parameters here are proportional constant (K_P) and either Integration constant (K_i) or derivative constant(K_d).

Adding Integration or derivative constant to system will obtain dabbed effect on the proportional constant influence and affect the total output response of the controller(Bhilai et al,2014).

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a) PI-Controller Transfer Function

PI: Proportional plus Integration

Hence, the transfer function of the system will be:-

$$Gc = K_P + \frac{K_i}{s} = \frac{u}{E}$$

b) PD-Controller Transfer Function

So, the transfer function of the system is :-

PD: Proportional plus derivative

$$Gc = K_P + s\, K_d$$

2.3.3. Triple mode controller Transfer Function

This is a common used control type which comprise the three effective parameters of proportional constant (K_P), Integration constant (K_i) and Derivative constant (K_d).

The total output response of the controller can be achieved by changing or re-setting the value of these parameters in a famous technique called PID Controller Tuning(Alia M.A et al,2022).

Hence, the transfer function of the system will be:-

$$Gc = K_P + \frac{K_i}{s} + s\, K_d$$

2.3.4. Closed Loop System Transfer Function

PID controllers are known to have three control modes: Proportional (P), Integral (I), and Derivative (D). The dynamic PID closed loop block system is represented in Figure 15. The three mechanisms respond to the error differently. Adjusting the controller's tuning settings can alter the reaction generated by each control mode. A PID controller is used in industrial control applications to control certain process variables, such as temperature, gas density, liquid flow, and pressure. PID controllers are the most precise and reliable controllers, which

use a control loop feedback mechanism to control process variables. Compared to other controllers, the PID controller provides output responses with negligible overshoot and steady-state error, which means the PID system will maintain the desired set point process value (Thirumurugan P.et al,2013).
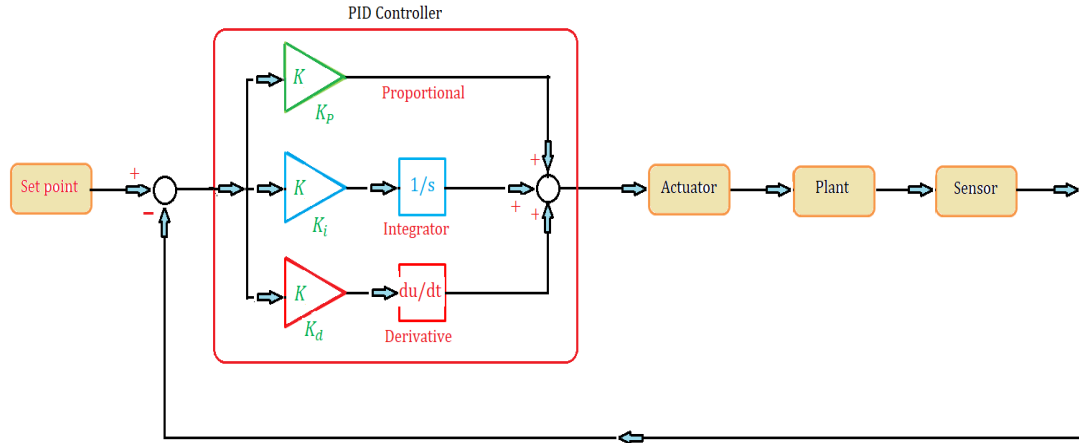
Figure 15 . The dynamic PID closed loop block system

The hardware design and the program design make up the two components of the control system design. The hardware design process includes the controller, sensor, and actuator selection. A controller is a tool that keeps a quantity constant with a set point. It is an electronic circuit or a mechanical-electrical device, like a gas density sensor. However, now, graphical programs for computer interfaces have assisted control development. To use a computer as a controller, the operating system of an old controller might be transferred into computer software. This is referred to as a computer-based control system. In this instance, a PID controller computer program is designed. This is accomplished by creating a flowchart for the controller as its initialization. After completing all design phases, K_P (proportional gain), K_i (integral gain), and K_d (derivative gain) of the PID control parameters are further determined. A method of trial and error is utilized to determine the control parameters. The suggested criterion is to discover K_P, K_I and K_d values by substituting several sets of control parameter values into the PID controller's algorithm. This acquires a set of K_P, K_I and K_d values that cause the steady-state error (E_{SS}) to fall within the specified range. This technique is the most straightforward, making the experiment easiest to execute and the outcome is exact and practical (Lokhande M.et al,2022).

The relation among the input (e(t)) and the output C(t) of the PID Controller, as shown in Figure 16, can be formulated in the mathematic model as follows:
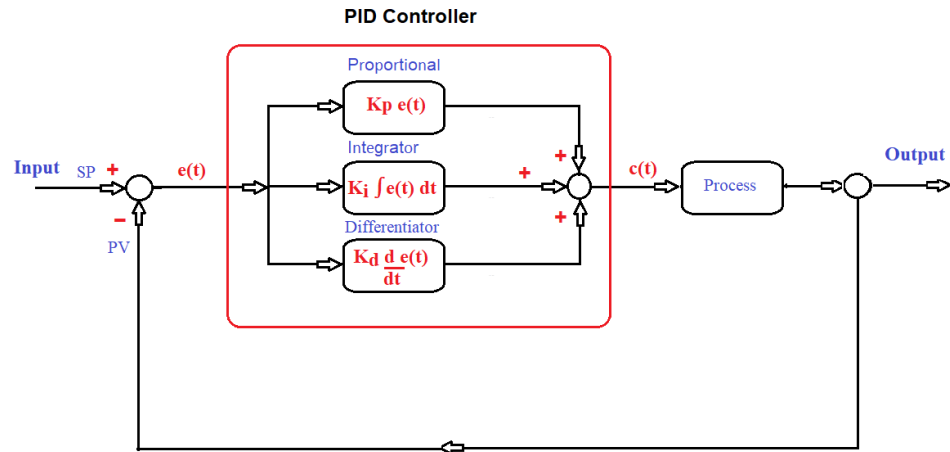
Figure 16 .PID Controller block diagram in time domain.

$$c(t) \ = K_P \ e(t) + K_i \ e(t) K_d \frac{de(t)}{dt} \tag{1}$$

Where: e(t) denotes the error value and can be expressed as

$$e(t) = \text{SP-PV} \tag{2}$$

Here, SP and PV are the set point and the process value, respectively.This relationship can be modelled in Laplace, as shown in Figure17, and written as
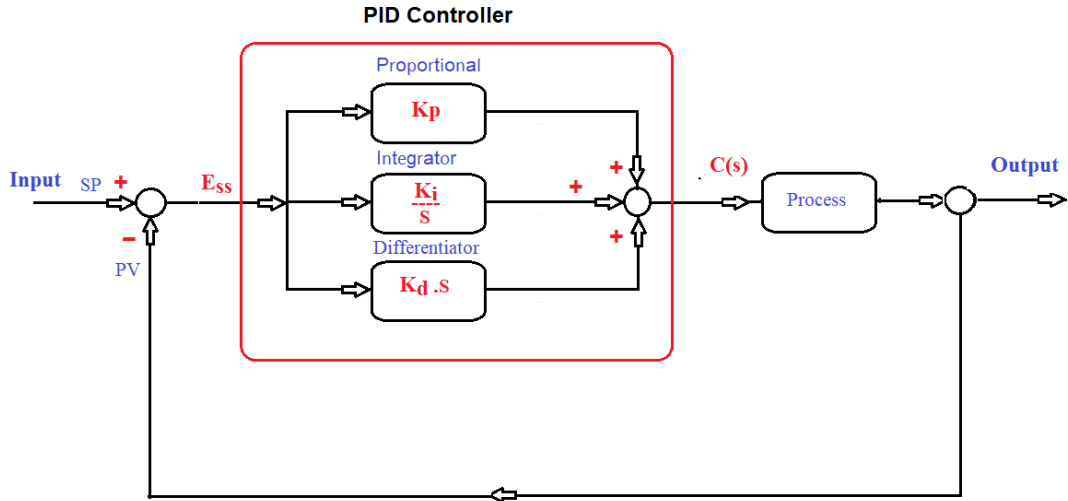
Figure 17 . PID Controller block diagram in Laplace domain.

$$C\ (s) = \ K_P\ + \frac{K_i}{s}\ + \ K_d\ s \tag{3}$$

Eq. (3) can be rewritten as

$$C(s) = \ K_P(1\ + \frac{K_i}{K_Ps}\ + \frac{K_d}{K_P}\ s\ ) \tag{4}$$

Define $T_i\ = \frac{K_P}{K_i}$ and $T_d\ = \frac{K_d}{K_p}$ as the integral time and the derivative time,

respectively, then Eq. (4) can be expressed as:

$$C\ (s) = \ K_P(\ 1 + \frac{1}{T_is}\ \ + \ T_d\ s\ ) \tag{5}$$

As known that for any gas density calculations, the following equation will be
applied

$$P*V = \ n*R*T \tag{6}$$

Where : $n\ \ = \frac{m}{M}$. , the Gas density can be written as

$$D\ \ = \frac{m}{V}\quad\frac{M}{R}*\frac{P}{T} \tag{7}$$

Where, the parameters associated with the density control shown in Table
3. shown below.

Table 3. Physical parameters.

Parameter Symbol	Physical Parameter	Unit
D	Gas density	Kg/ m^3
m	Mass	Kg or gm
M	Molecular weight	gm. mol^{-1}
N	The number of moles	
P	The pressure	Pa
R	Ideal gas factor = 8.31	
T	Absolute temperature	kelvin
V	The volume	m^3

Note that PID is a common method in control system. PID consists of the three controllers K_P, K_i, and K_d. Each action controller has its own advantage. Proportional action controller has fast rise time, Integral action controller is able to reducing error and derivative action controller is able to dampen overshot or undershot. These three controllers are combined to get output with fast rise time and a small error (David R.et al,2021).

2.3.5 PID Controller parameters Action

Typical Response of Feedback Control Systems, consider response of a controlled system after a sustained disturbance occurs (e.g., step change in the disturbance variable).The following figures will explain the output system response according to each controlling element of PID controller(Bhilai et al,2014)(Alvarez de M.et al,2017).

1- Proportional Action

In the case of pure proportional control, the control action is simply proportional to the control error. The variable ub is a bias or a reset. When the control error e is zero, the control variable takes the value $u(t) = u\ b$

Bias ub is often fixed to (umax + umin)/2, but can sometimes be adjusted manually so that the stationary control error is zero at a given set point.
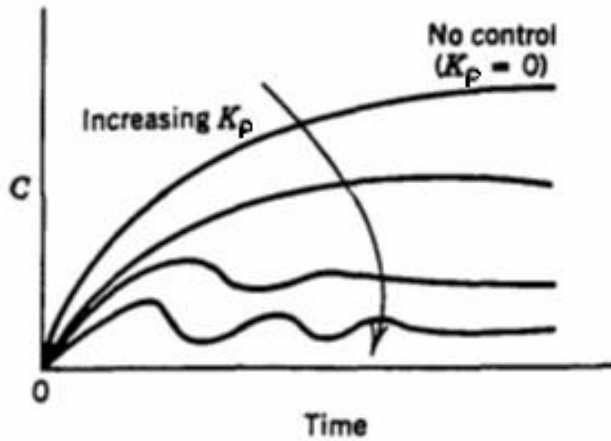
Figure 18 . Proportional control: effect of controller gain.

2-Integral Action

Making ensuring that the process's output in steady state complies within the set point is the integral action's primary goal. In steady state, proportional control typically has a control error. For integral action, a slight positive error is always going to result in a rising control signal, while a small negative error will always result in a reducing control signal. The steady-state error with integral action will always be zero, as shown by the straightforward reasoning that follows.
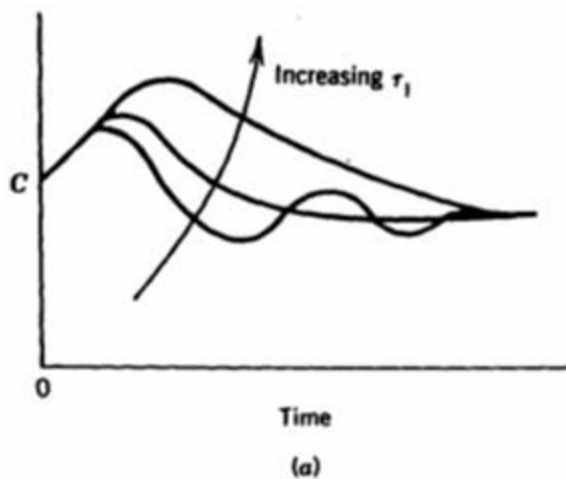
Figure 19. PI control: (a) effect of reset time.
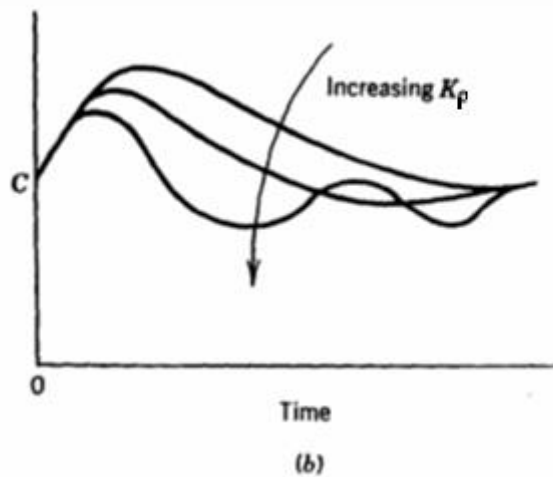
Figure 20. PI control: (b) effect of controller gain.

3-Derivative Action

The action of a derivative is used to increase closed-loop stability. The following intuitive explanation of the instability mechanism is provided. It may be some time before an alteration in the control parameter is apparent in the process's output due to the dynamics of the process. As a result, the system of controls will react slowly to an error. It is possible to interpret the behaviour of a controller both proportional plus derivative action as if the control were set proportional to the output of the Process that is predicted by extrapolation the error using the tangent of the error curve.
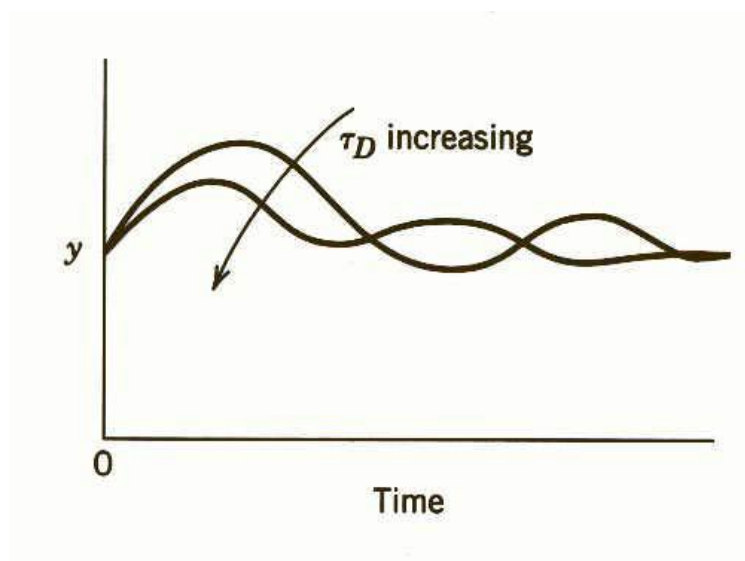
Figure 21. PID control: effect of derivative time.

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For summarize the action of PID controller element, we can refer to the following figure.
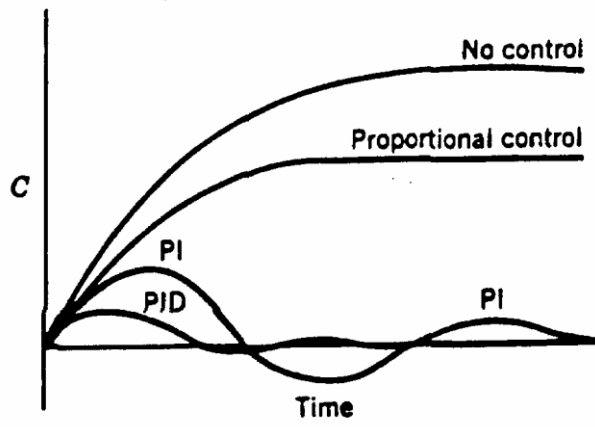
Figure 22. Typical process responses with feedback control.

2.3.6 PID Controller parameters Comparison

Here, we will shows the main differences between types:

- P-Simplest controller to tune (K_P).

- Offset with sustained disturbance or set point change.

- PI-More complicated to tune (K_P, T_i).

- Better performance than P-No offset.

- Most popular FB controller.

- PID-Most complicated to tune (K_P, T_i, T_d).

- Better performance than PI-No offset.

- Derivative action may be affected by noise.

2.4. **PID Controller Tuning**

Basically, there are two types of PID tuning which are:-

2.4.1 **Manual PID Controller Tuning**

A controller can be easily tuned through trial and error, but this method is time-consuming and does not always result in sufficient performance. The quality of the controller is frequently judged by the reaction y to a square wave or step. Performance standards include overshoot, undershoot, and rising time. The controller's high frequency and lower frequency components can be tuned separately, beginning with the high- frequencies component, according to a technique known as zone-based tuning. This suggests that a PID controller tunes the P- plus D-actions before tuning the I-action(Jabbar A.K. et al,2018)).A sample flowchart showing the steps to be taken for tuning the PID-controller is shown in Figure 23. In this instance, the step response overshoot is related to stability margin for the control system, serves as the performance criterion. Low stability margins result in a more oscillatory behaviour, while high stability margins typically result in low overshoot. Process operators can easily apply this strategy because it necessitates little to no expertise of the controlled process. The procedure's numerical values are guidelines derived from experience. The drawback is that not much is known about the system's robustness. Before the final parameters are established, numerous iteration steps might be required(Van der Zalm et al,2004).
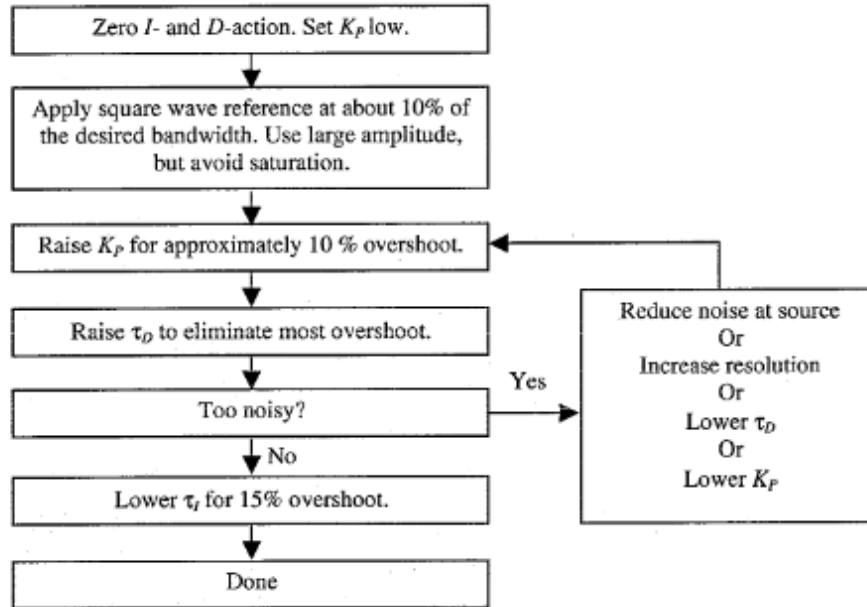
Figure 23. Flowchart for the manual tuning steps of a PID-controller

2.4.2 Auto PID Controller Tuning

The science of regulating systems offers a variety of tuning techniques that are based on a few easily obtained empirically aspects of the process dynamics. The parameters of the step response are typical time-domain characteristics.The final gain and period are typical aspects of the frequency-domain. Here, we'll give a thorough overview of tuning methods for well-known ones.We can rely on the rules, laws of these methods to quickly acquire the system response parameters when designing or programming any supported software in the field of control systems.

1-*The Ziegler-Nichols design method:*

The most often used techniques in process control for choosing a PID controller's parameters are Ziegler-Nichols design approaches. The main techniques for tuning PID controllers are Ziegler Nichols tuning methods (ZN tuning methods). Step response method and ultimate frequency method are the names of the two techniques.The open-loop step response of the system serves as the foundation for the unit step response approach.Two parameters delay L and time constant T define the process's unit step response. At the inflexion point, where the slope of the step response has its maximum value, these are calculated by drawing a tangent line.

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The process parameters are determined by the intersections of the tangent and coordinate axes, as shown in Figure 24, and they are employed in calculating the controller parameters(Korsane et al,2014).
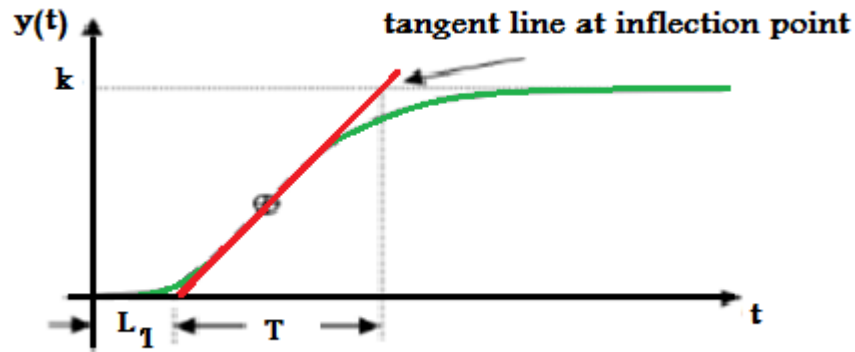
Figure 24. Response curve for Z-N tuning method.

Table 4 displays the PID controller parameters derived from the Ziegler-Nichols step response approach.

Table 4. PID tuning table by Ziegler-Nichols method.

Sr. No.	Type of controller	K_p	T_i	T_d
1	PID	$1.2T/L_1$	$2L_1$	$0.5L_1$

Because there is no (Z-N) tuning table for the discrete Ziegler-Nichols tuning method present for rejecting the disturbance of load with reference to variation in the step that will give as the simple oscillation damping response with peak have to value are (1/4) of the previous peak, the PID controller in the discrete-time must take the sample time into consideration in the calculation. Both first- and second-order systems can be solved using this technique(Jain et al,2019).

2- *Method of Ziegler-Nichols continuous cycling*

Frequency domain analysis presented by Ziegler and Nichols is based on the ultimate gain Ku; and the ultimate period Tu. Table 5. shows the parameter controller settings .

Table 5. Parameters for the Ziegler-Nichols continuously cycling method.

Controller type	K_p	τ_I	τ_D
P	$0.5\ K_u$	-	-
PI	$0.45\ K_u$	$T_u/1.2$	-
PID	$0.6\ K_u$	$T_u/2$	$T_u/8$

The continuous cycle method has the drawback that it forces the system to become unstable, which might occasionally result in hazardous circumstances. Furthermore, depending on the parameters of the process, the resulting closed loop behavior can be significantly different.

3- *Method of Cohen and Coon*

Cohen and Coon based the controller settings on the three open loop step response parameters, Ti, and K. Rejection of load disturbances serves as the primary design requirement. By positioning closed loop poles, a quarter of a decay ratio is the goal of the strategy. Their suggested controller settings are listed in Table 6.

Table 6. Cohen-Coon parameters settings.

Controller type	K_p	τ_I	τ_D
P	$\dfrac{1}{K}\dfrac{\tau_1}{\theta}\left[1+\dfrac{\theta}{3\tau_1}\right]$	-	-
PI	$\dfrac{1}{K}\dfrac{\tau_1}{\theta}\left[0.9+\dfrac{\theta}{12\tau_1}\right]$	$\dfrac{\theta\left[30\tau_1+3\theta\right]}{9\tau_1+20\theta}$	-
PD	$\dfrac{1}{K}\dfrac{\tau_1}{\theta}\left[1.25+\dfrac{\theta}{6\tau_1}\right]$	-	$\dfrac{\theta\left[6\tau_1-2\theta\right]}{22\tau_1+3\theta}$
PID	$\dfrac{1}{K}\dfrac{\tau_1}{\theta}\left[\dfrac{4}{3}+\dfrac{\theta}{4\tau_1}\right]$	$\dfrac{\theta\left[32\tau_1+6\theta\right]}{13\tau_1+8\theta}$	$\dfrac{4\theta\tau_1}{11\tau_1+2\theta}$

This technique uses one extra parameter, however the outcomes aren't considerably different from those applying Ziegler Nichols settings is recommended because low damped systems with closed loops occur from the decay ratio being too small.

2.4.3 Steps for Improve PID Tuning

1- Identify the loops and objectives.

Simply identifying which PID loops need tuning is the first step.Since badly tuned systems can function for a long period without having visible implications, this may not be immediately apparent.When users notice a system that's malfunctioning, such as a system that oscillates or goes beyond the alarm limits, a reactive strategy might then be used.Active users can track down underperforming systems by historizing, analyzing, and monitoring important performance data. A issue may be indicated by frequent alarm trips, persistent deviation situations, out-of-spec item, or controlled equipment operating at higher extreme than usual. One proactive tactic is to determine whether the core cause is due to mechanical problems, process circumstances, PID controller adjusting, or a combination of these factors.These problems will be identified through careful analysis, that will also lead to the development of an action plan for correction that needs to have the ultimate control objective in it. The acronym "SIMPLE" offers suggestions for defining good control. For every given loop, there may be a number of linked primary control goals. Think about regulating the liquid level inside a reflux drum (Figure 25).
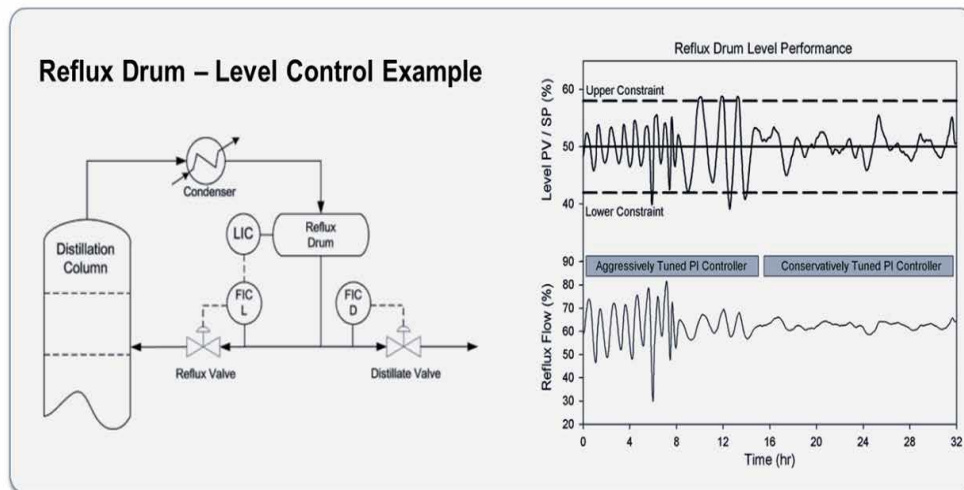

Figure 25 . Evaluating the process and determine objectives.

2- Process-stepping or bumping.

The purpose of gathering data is to gather enough information to describe the properties of a system process , depict its dynamic behavior, and clarify how the PV responds to changes in the CO. Simply essence, the data has to illustrate how the physical process's cause and effect are related.The next thing to do is to perform the bump test, which includes fast and significantly changing the CO to produce a discernible PV response which clearly overcomes any random noise. The ideal response is not less than five times larger than the noise. Figure 26 depicts different open-loop as well as closed-loop tests where the carbon dioxide (CO) is changed while the photovoltaic (PV) response is being measured. Data sampling rates, which should be at least 10 times greater than the process's time constant, are an essential part of testing to make ensure that is enough precision for computations. Following are some sample rate suggestions depending on the various process types: It is optimal both flow and pressure to last under 2 seconds.. Level: For smaller tanks, faster sampling takes place every 1 to 5 seconds. Temperature, Quick: 5 to 15 seconds Slow temperature measurement: 15 to 30 seconds pH, Concentration: five to thirty seconds .To guarantee that the test data is appropriate and that the underlying system dynamics are not hidden, there are a number of additional circumstances and difficulties that can alter feedback signals. Each of them must be taken into account. These conditions are in a stable state. Making sure the process starts at a steady level (neither rising nor decreasing) prevents dynamics that are actually in motion from influencing the results noise.To make the data easier to evaluate, testing should put the system through enough stress that the PV response is seen to be at least five to ten times bigger than signal noise disturbances.Testing personnel should monitor the process systems associated with the PV being tested to ensure no disturbances outside of the test actions (such as other equipment changing operation, product changes, etc.) are affecting the data .

- Underlying problems: Testing personnel should also look for other problems such as valves that are sticking or have large hysteresis as these will often return bad data .

- Variable process ranges: It should always be done testing over the whole operating range with excellent data recorded, and the following step will be to model the

process. Some processes display varied behaviors that depend on what portion of a process's range it operate in.
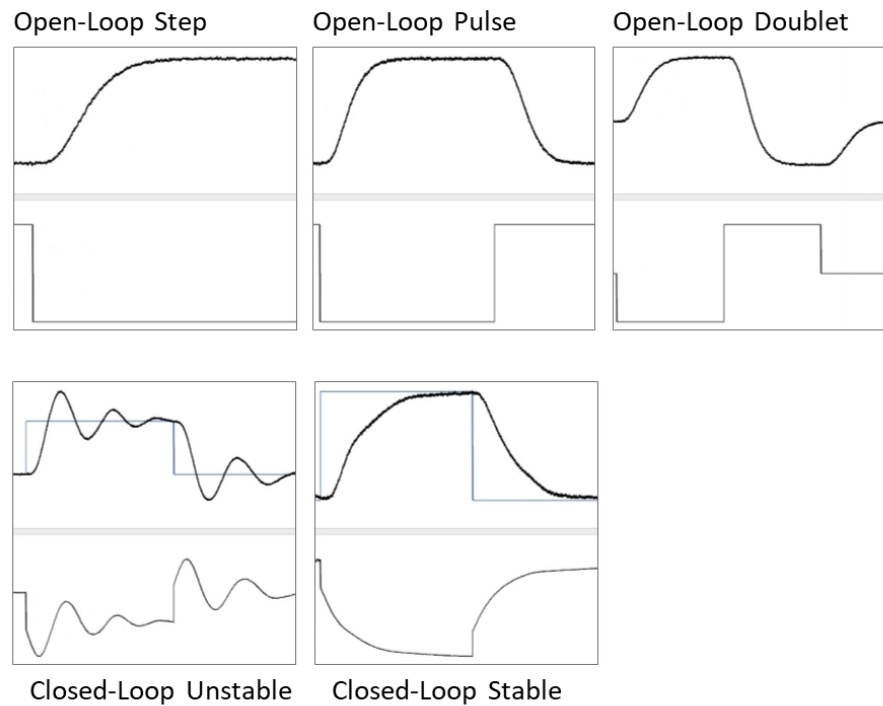
Figure 26. Step or bump for control output.

3- Model the process.

The gathered data must be used by tuning software to build a mathematical process model, and the model's quality determines how well the tuning works. To make this stage easier, users should have a basic understanding of how the process works; They might also have to input this data into the tuning program.Process action comes in two flavors. For processes with direct action, raising CO will also raise PV. Imagine a heat exchanger with a modulating steam valve that, when opened, raises the temperature. The opposite is true for reverse acting processes, that is when a surge tank's modulating discharge valve is opened to lower the level.Two other forms of process behavior are also present (Figure 27).When all conditions are kept constant for self-control processes, additionally known as non-integrating processes, the PV will attempt to reach a steady state. A heat exchanger operates in this manner.However, non-self-regulating processes, Processes that are frequently referred as the process of integrating only have one equilibrium point where they reach a steady state. and continue to go up or down even when all other parameters

are maintained constant. This is how a surge tank behaves; it is continuously filled, but the level will fluctuate depending on whether At the ideal equilibrium point, a discharge valve is precisely in place.
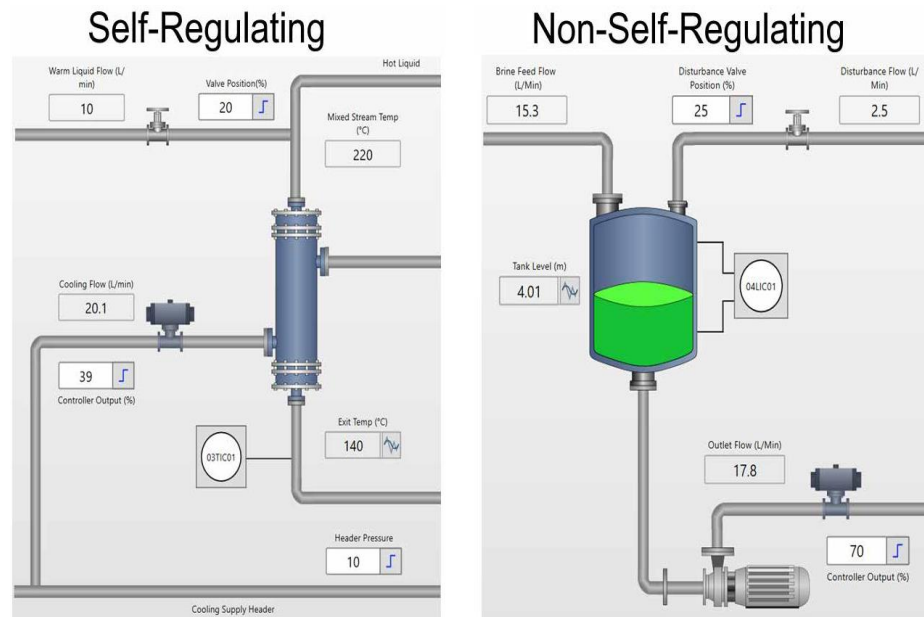
Figure 27. Involves fitting process model

4- Tune the PID loop.

The primary responsibilities up to now have been understanding the tuning aim, collecting data, plus fitting a model. The precise PID tuning specifications are now in focus. Basic loops can be crudely tweaked by hand, but by handling all the arithmetic and display settings, specialized tuning software offers users several benefits. This type of software is capable of quickly analyzing a wide range of models as well as data sets, on and offline, while it may also be used to correct data errors such tests that don't begin at steady state.The user's control platform should be firmly connected with the tuning software for the optimum outcomes and ease of use. This facilitates data collecting and guarantees that the control platform and the tuning software both utilize the same computations, terminologies, and variables.The ideal situation is for the tuning software to be completely integrated by means of native menus and faceplates, as well as with the control platform.Figure 28, shows three tuning options for PID loops: aggressive (rapid),moderate, and conservative (slow). Additionally, not all processes require the use of every PID control component. For different processes, you can opt to use simple P alone, PI, or full PID control. Software tuning systems can provide tuning maps that depict all potential outcomes,

allowing the user to select the optimal one.Some operations, like surge tanks, might merely need cautious tuning to prevent overfilling or underfilling. To preserve quality, some procedures, including the heating of crucial products, may require very rigorous management.
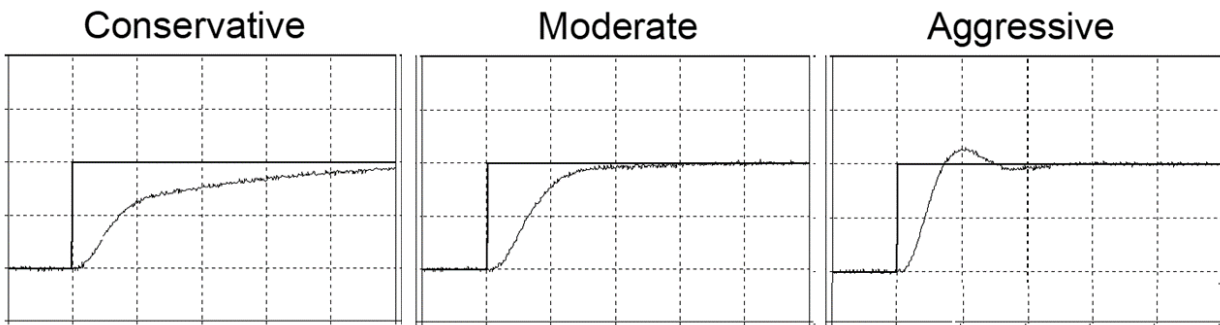
Figure 28. Uses software to analyze the test data

5- Test by implementation

PID tuning parameters have to be performed and tested on an active, functioning system to ensure they work as intended.Whenever the control platforms and the tuning program are closely integrated, this process is made simpler (Figure 29). This makes it possible to quickly apply and change groups of settings whilst the system is in operation. When tuning settings are modified, users must be ready to convert the loop to manual mode or recover the original tuning values.In testing, the SP is modified to ensure that it is tracked correctly and a change in processes load or other disturbance is introduced to ensure that the PV recovers promptly. With minimal or no overshoot and out of control CO action, well-tuned loops react rapidly enough to fulfill user goals. Be mindful that if the loop is first observed at steady state, it's impossible to examine the reaction. PID controllers have error-based, therefore for the controller to respond, an error has to be introduced.
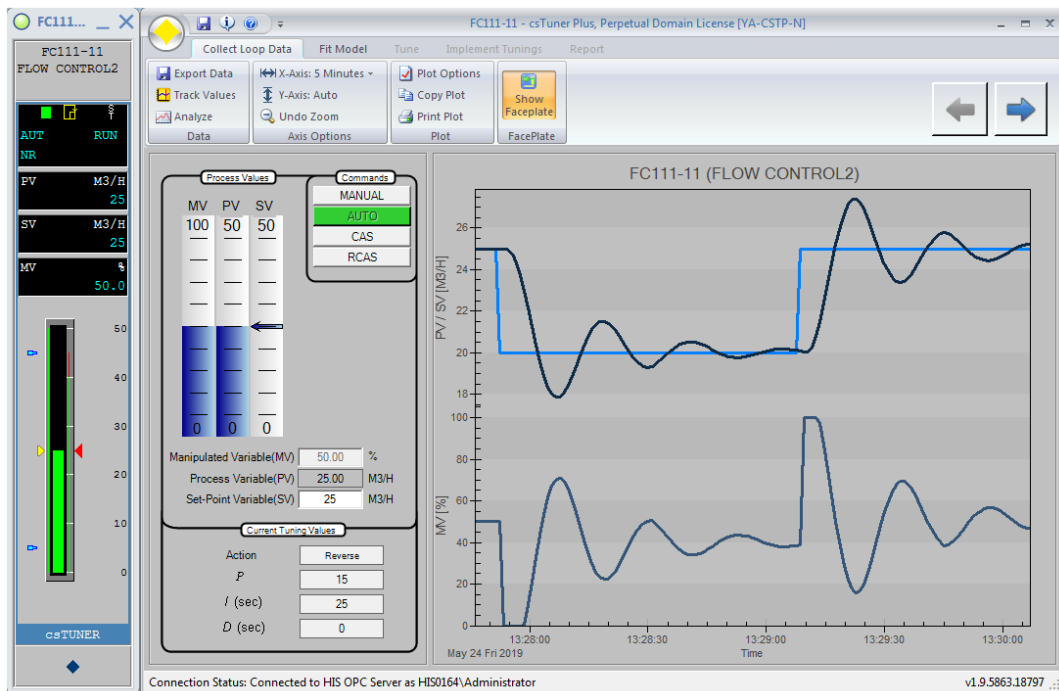
Figure 29. Crucial for testing the calculated tuning parameters

6- Documentation.

The final and maybe most underappreciated phase in the loop tuning process is documentation. When a loop is adjusted and performing well, the team breathes a sigh of breath and gets ready to move on. However, the work is not finished without thorough documentation, which includes:-

Who: Who changed things?

What: The raw data, the loop that was tweaked, the settings that were initially in place, the settings that were advised, and the settings that were ultimately applied?

When was the loop evaluated and modified?

Why: What are the objectives of the loop tuning?

A record for future work is provided by proper documentation (Figure 30). The top options for recording the aforementioned subjects, including real-world and simulated response trends, are often provided by professional loop tuning software, ideally in an accessible PDF report format(Bob Rice et al,2019).

43
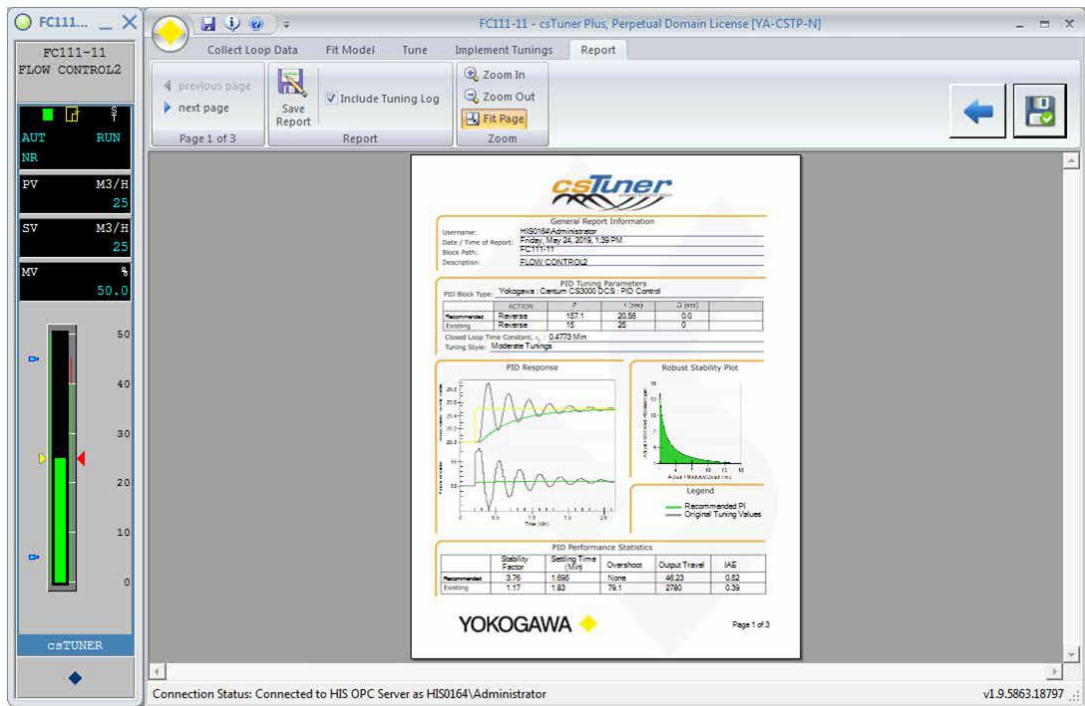
Figure 30. Documenting for the process

CHAPTER THREE

SF6 GAS MONITORING AND CONTROL SYSTEM REQUIREMENTS

3.1. Planning a Control System Design Strategy

To implement any industrial project we need to plan a control system design first with the following procedures:-

1- Determining the input and output process parameters.

2- Designing the process control flow chart.

3-Choosing the suitable software tools and other requirements.

4- Choosing the suitable hardware and other requirements to physically execute the project.

5-Determining how to get output results by software and hardware tools.

6-Determining how you can analyze, represent and simulate the results.

7-Determining the acceptance criteria used to evaluate the results.

8-Determining the efficiency of the project compared with the desired objective.
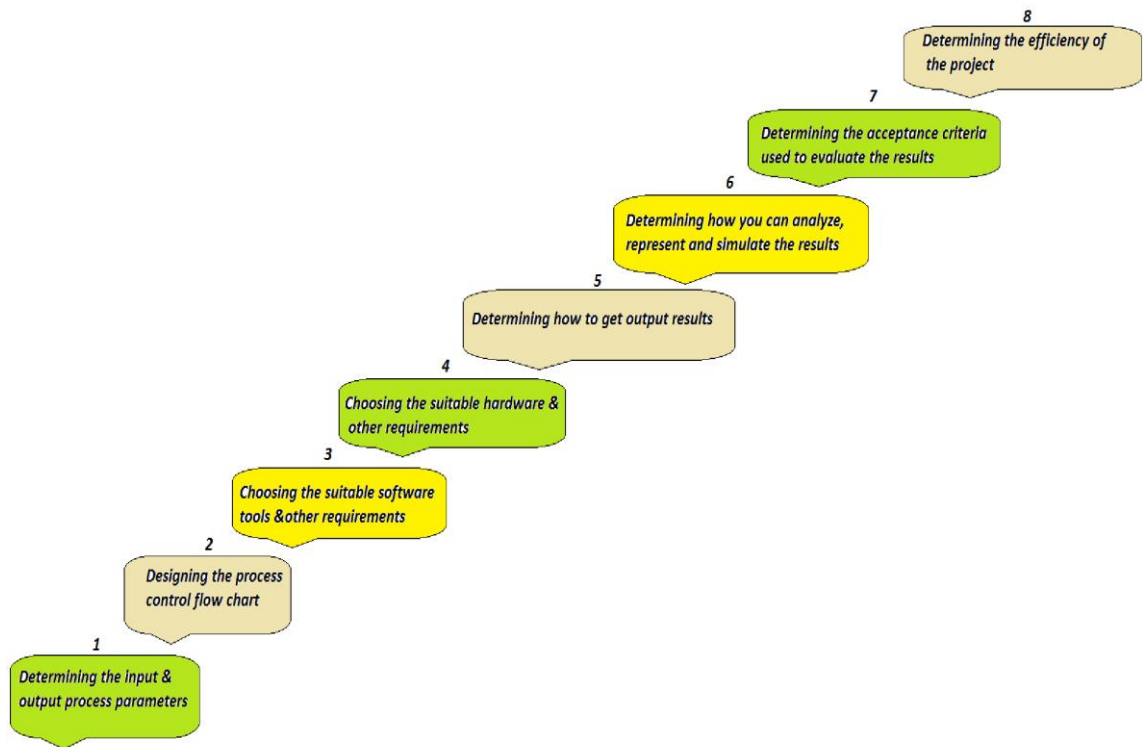
Figure 31.   Planing a Control System Design Strategy procedures

3.2. Software Components

3.2.1.   Arduino Interface Program

The scripting code for Arduino does not specify a specific computer language or microcontroller, but it does outline the fundamental logical stages to create control using the PID technique. Additionally, it omits some information that is usually needed based on the specific control issue and the controller in use.You can use the Arduino programming language, which is similar to C, as a guide to create your own PID function. The set point potentiometer's variables and pin codes must be specified. (gas density), proportional solenoid valve drive pin (relay), and gas sensor pin. When writing the sketsh Arduino program,each input and output pin should programmed to do its required function.

3.2.2.   LabView Program Sections

  In this study we will use two of an affective and familiar softwares to work as PID system project simulators.which are:

1- LabView software:

A graphical language for programming called LabView is used to construct apps rather than lines of text.LabView employs data flow programming, which the flow of data defines execution order as opposed to text-based language programming, which instructions drive program execution. Specifically, LabView VI has two partss, which are:-

   A- Front Panel:

All of the input & output variables are present.The inputs could be sensors, and the output could be a true or false case, a graphical indicator, or a numerical indicator. Additionally, LabView comes with a number of wizards that can help you create applications and quickly configure your computer-based instruments and peripheral devices. Using a variety of tools and objects, you may create a user interface in LabView. The front panel is the term for the user interface. After that, you add code to control the front panel items by using visual representations of functions.

   B-Block Diagram:

Logical function blocks are present. The structure of the block diagrams resembles a flowchart in certain respects. When the software is open, users engage with the Front Panel. Users can modify inputs, operate the application, and view data being updated in actual time. The block diagram has a terminal for each control or indicator on the front panel. When a VI is executed, control values flow via the block diagram, in which they are employed in the functions in the diagram, and the outcomes are transferred into additional functions or indicators over wires(Adams T. Et al,2012).For instance,we utilized the LINX software, which is the latest method of programming Arduino, to create the VI Block Diagram. In order to communicate with popular embedded platforms like Arduino, LINX offers simple-to-use LabView

VIs. Although they have distinct names, the LINX functions perform similarly to the LIFA(LabView Interface for Arduino) function.

The control and indicator connections of the front of the device, as well as a number of nodes, constants, and wires, are all represented in the VI block diagram. Different functions, subVIs, and programming structures make up LabView's nodes.For the Arduino platform, we programmed using a variety of LINX functions, including:

Communication is started through the Open Function. The COM Port which Arduino is attached to is visible. The Open function is where every program begins.

- The sensor output voltage is compared to the voltage threshold defined by the user after the Analog Read Functions reads the value of the given analog input channel;
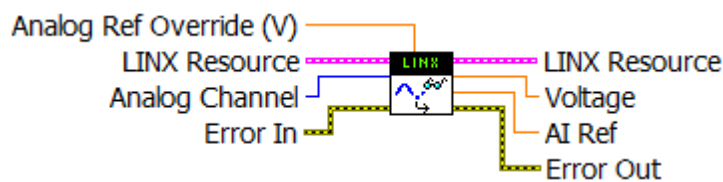
- We can choose the Arduino's digital input address by using the digital write function. The value is connected to or sent while the Output Values input is active;
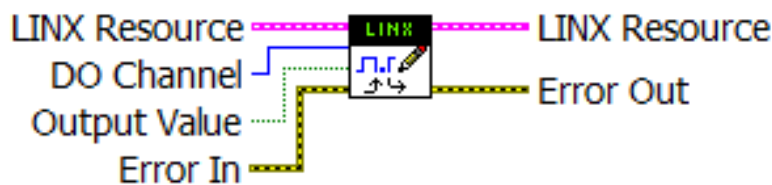
- The program's conclusion is managed by the Close Function. Every program must end with the Close function;
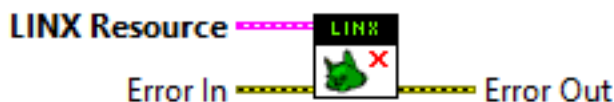
-We may view the loop rate in Hz using the Loop Frequency Function.

- If an error happened, it will be made clear via the Simple Errors Handler Function. This VI returns an error explanation and, if desired, displays a window that indicates if an issue occurred.
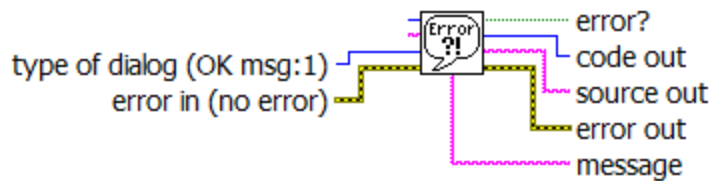
- The larger or equivalent? If the resulting sensor voltage is above or equal to the voltage threshold, the function returns TRUE. This function yields FALSE in all other cases.

- The VI's Bock Diagram also features a While loop. While loops run the code inside them until a condition is met (Bogdan et al,2018).

3.3. Hardware Components

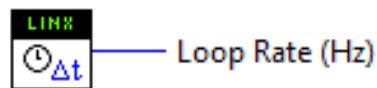In the hardware section, we will deals with many elements to complete building the control system.

3.3.1. Arduino Open-Source Device

Arduino is an open-source electronics prototyping platform cased on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists and anyone interested in creating interactive objects or environments.Arduino Uno is one of Arduino family versions of the motherboard which can be use in this project as the variety of inputs and outputs which can be used for sensors or to control lights, motors and other actuators are provided another very pleasant solution implemented in Arduino board is the programming language created especially for the needs of the

microcontroller and Arduino development environment(based on Processing - also open source programming language). To communicate with software running on computer Flash, Processing are recommended.

Open source and relatively new concept cause the fact that documentation is provided mostly in wiki-like and forum form which is bothersome when meeting problems during development process. Experience shared with other developers helps to improve following versions of Arduino board but lack of the old fashioned technical specification forced me to look through countless data in order to find needed information. The ATmrga328 is a component of the Arduino microcontroller. It contains a crystal oscillator with a frequency of 16 MHz, 6 analog inputs, 14 digital I/O pins, 6 of which may be used for PWM outputs, an USB connection, a power socket header, with a reset button.The main difference between other solutions available is the USB-to-serial driver chip. Instead the ATmega8U2 programmed is supported as a USB-to-serial converter . Battery power, a DC adapter, or USB can all be used to power the board. The power supply is automatically chosen.The power connector's Gnd as well as Vin pin heads are where the battery should be put, together with the USB port or power jack. Because of the fact that voltages lower than 7 volts cause the 5 volt onboard pin to become unstable and voltages greater than 12 volts can cause the regulator of voltage overheat and directly harm the board, the suggested range for supply is between seven and twelve volts despite restrictions of 6 to 20 volt(Fetene et al,2017).

The Arduino system is open source -all hardware (made by Arduino distributors) has the schematics and PCB layouts available online.Another Arduino specifications which are:-

1-Open Source Bootloader.

The bootloaderis what runs on the chip before the program is run. It boots the chip and executes the program.

2-Open Source Development Kit.

The development kit what you use to program an Arduino board is also available online. It is free, open-source.
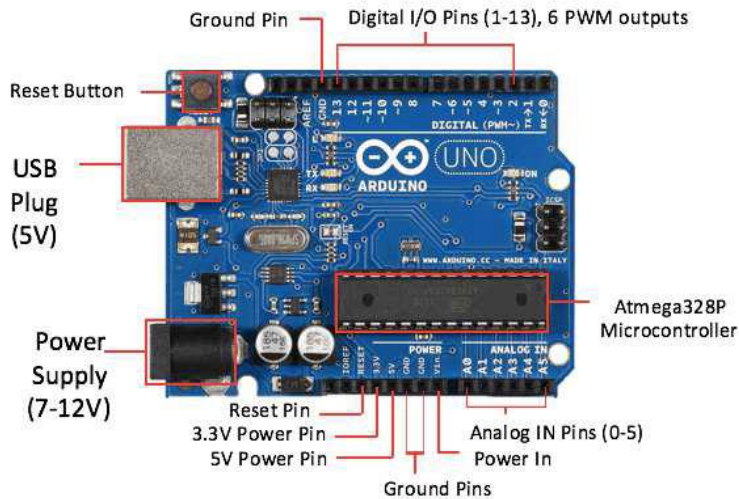
Figure 32. Arduino Uno Microcontroller Board

3.3.2. Sensor for SF6 Gas Density

Quarz tuning fork for special electronics SF6 gas density monitoring.To track insulating gas levels, the Trafag gas densities sensor model 8774 was invented. The energy distribution business now has new avenues to pursue in order to realize thorough trends analysis and monitoring thanks to this special patented sensor technology. It provides a digital or analogue output signal while directly and constantly measuring the gas density. The digital output version additionally offers a signal for the gas temperature.

Figure 33. Sensor for SF6 Gas Density

Advantages:

1-A continous digital or analog output signal that can be used for SF6 analysis of trends.

2-Wide density spectrum.

3-Additional sensor temperature output (available only in digital form).

4-Extremely high drift plus no signal.

5-Application in the outdoors without additional protection.

6-EMC, or electromagnetic compatibility.

7-Measurement for all gas densities .

8-Facilitates adherence to rules governing greenhouse gas emissions.

The way that the electronics gas density sensor works is:

A quartz oscillator's constant resonant frequency in vacuum is contrasted with the resonance frequency of a quartz crystal located in the sample gas. The density of a sample gas relates to the difference in resonance frequency. An output signal that is either analog or digital is created using this difference. The duration of the pulse of the frequency signal can be used to assess temperature with the digital variant (WIKA 2022).

3.3.3. Monitor for SF6 Gas Density

The advantages of the tried-and-true mechanical monitor built on a superior reference chamber are combined with the special electronics gas density sensor in the Hybrids SF6 gas density monitor. The combined system enables remote monitoring and trend analysis in addition to local switches and readout. The small, all-in-one gadget, which has a single pressure port, performs dependably and without maintenance in both tough indoor and outdoor environments. Over a broad spectrum

of temperatures and altitudes, it is reliable

Figure 34. SF6 gas density Monitor

Advantages:

1- 1-Analog output signal with mechanical switch plus continuous output signal for trend analysis.

2-High vibration and shock resistance.

3. There is no electrical contact bouncing.

4-Exceptionally high electromagnetic compatibility.

5. No alarm for Low temperature.

6-Maintenance-free; switch points do not need to be recalibrated.

7- Makes it easier to follow greenhouse gas rules.

The reference chamber's mechanism of operationis:

A bellows system compares the gas density in the SF6 compartments to the gas concentration in the reference gas chambers in the monitor. The bellows system activates a number of micro switches if the gas density changes. If the temperature of the gas varies, which also affects its pressure, the reference chamber experiences the same pressure differential. Pressure variations brought on by temperature do not cause any false alarms. Different warning signals can be activated by one to three

galvanically insulated micro switches. A visual examination for the SF6 gas densities as gas pressure at 20°C is possible with an optional SF6 indicator (WIKA ,2017).

3.3.4. Proportional solenoid valve

An electro-mechanical device called a proportional solenoid control valve adjusts flow or pressure in accordance with an electrical signal. A magnetic field is created when power is applied to the solenoid coil, controlling the position of a plunger inside the valve. In a range of settings according to changing power input, the plunger pulls against the spring force to open the valve. Particularly in compared to conventional solenoid valves, which can only be fully open or fully closed, this enables greater flexibility and control. This design's valve is depicted in Figure 11. It needs a 12 VDC power source and is generally closed (NC) .An extra power supply was integrated into this design because the Arduino only delivers 5V(Valve,2021).

Figure 35. Proportional solenoid valve

3.3.5. Power Supply and Accessories

1- Power supply:

It is an electronic device that converts the AC voltage produced by a transformer through DC voltage such as 12 VDC, 9 VDC, and 5 DC so that it may be used to power the Arduino microcontroller and other equipment.

2- Requirements and accessories:

Such as Bread board for fast wiring experiment circuits, Relay element for switching and control the load, Potentiometer resistor for set point value physical setting, and wire probs.
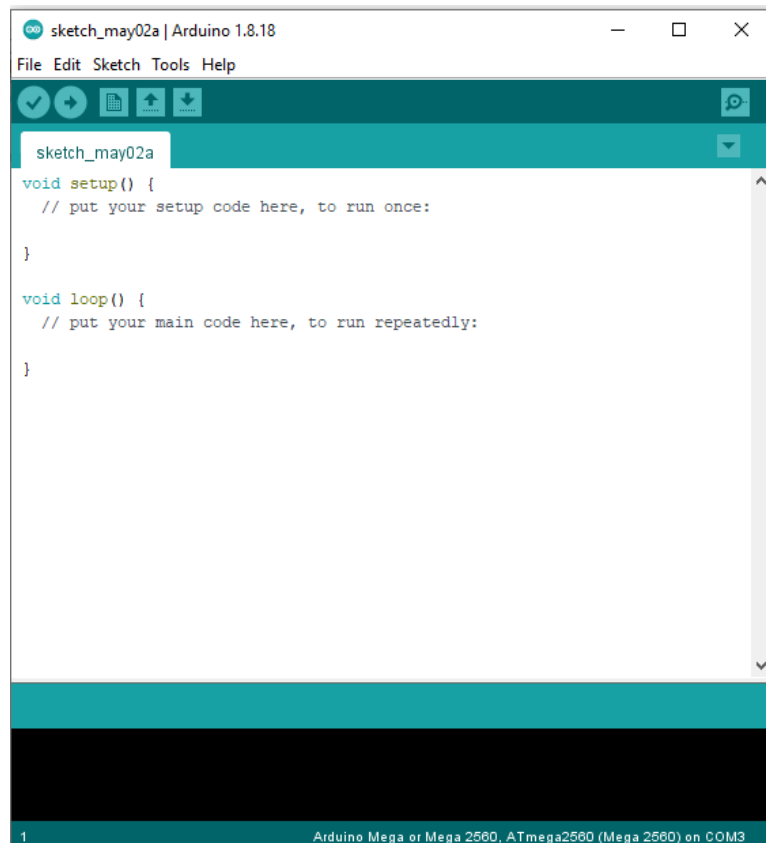
3- Connections:

The proportional solenoid valve power connection should supply separately of Arduino board, because the Arduino board can be powered via an USB link to a computer or by a different DC power source placed into the Arduino's circular DC power connector.

3.4. Building PID LabView- Arduino Simulation System

3.4.1. Writing Arduino Interface Program

The program code shown below is written in the C-like Arduino language which you can use as a guide to developing your own PID function. You must define the variables and each input, output pin numbers and also for the set point potentiometer (desired SF6 gas density), relay drive output pin (valve), and SF6 gas sensor input pin(Leonard et al,2022).

Figure 36 . Arduino program Sketch screen

In order to write the sketch program, you should determine the following considerations:

1-Digital input pins.

2-Digital output pins.

3-Analogue input pins.

4-Analogue output pins.

5-Set point value.

The following instructions represent a PID Arduino Sketch program:

```
--------------------//Calculates the PID  parameters value//--------------------

Actual = analog Read (gas sensor);(

Error = Set Pt - Actual;

If (abs(Error) < Int Thresh){ // prevent integral 'windup'

Integral = Integral + Error; // accumulate the error integral

{else}

Integral=0; // zero it if out of bounds

{

P = Error * kp ; // calc proportional term

I = Integral * ki; // integral term

D = (Last-Actual) * kd; // derivative term

Drive = P + I + D; // Total drive = P+I+D

Drive = Drive*Scale Factor; // scale Drive to be in the range 0-255

if (Drive < 0) {  // Check to go.

Digital Write (Relay of valve ,LOW); // change as needed

{

else { // depending on the sign of Error

Digital Write (Relay of valve, HIGH;(

{

if (abs (Drive)>255} (

Drive=255;

Last = Actual; // save current value for next time
```

3.4.2 Arduino Module System simulation and Operation

As shown in Figure 37, the simulated Arduino PID Monitoring and control system consists of an Arduino module as the interface Module between the sensor field and the user, an SF6 gas density sensor, a relay module, a breadboard, and other different electronic elements. The system is designed to operate as a PID gas leakage and density monitoring and controlling system. The system cycle starts with the gas density sensor for sensing the gas status in the GIS equipment. The analog input parameter passes through the Arduino AI ports as a process value. The result of the PID system will appear as an output process response at the output Light Emitting Diodes (LEDs). According to the comparison process for the input parameter with the PID system set point, the system will show the blinking alarm indicator with a sound buzzer when the process variable value exceeds the upper or lower pre-determined limits inside the Arduino PID program to make attention to the system state (Nakamori et al,2021). The next step after the alarming state will be according to the system-designed function since the process variable value tends to approximate the set point density value. This means that if there is a difference between the process SF6 gas density value inside the GIS equipment section and the set point value due to leakage or any disturbance, this will activate an output signal to the relay module through the digital output port for Arduino module to open the solenoid valve and make an extra SF6 gas amount passes through from the SF6 conservator source to the GIS equipment to increase the gas amount and reach the desired set point of the system and satisfy the required safety gas density required. The system cycle will continue whenever the gas density change and is not equal to the set point. That is what maintains the gas density inside the GIS equipment and protects the GIS substation from any dangerous disturbance.
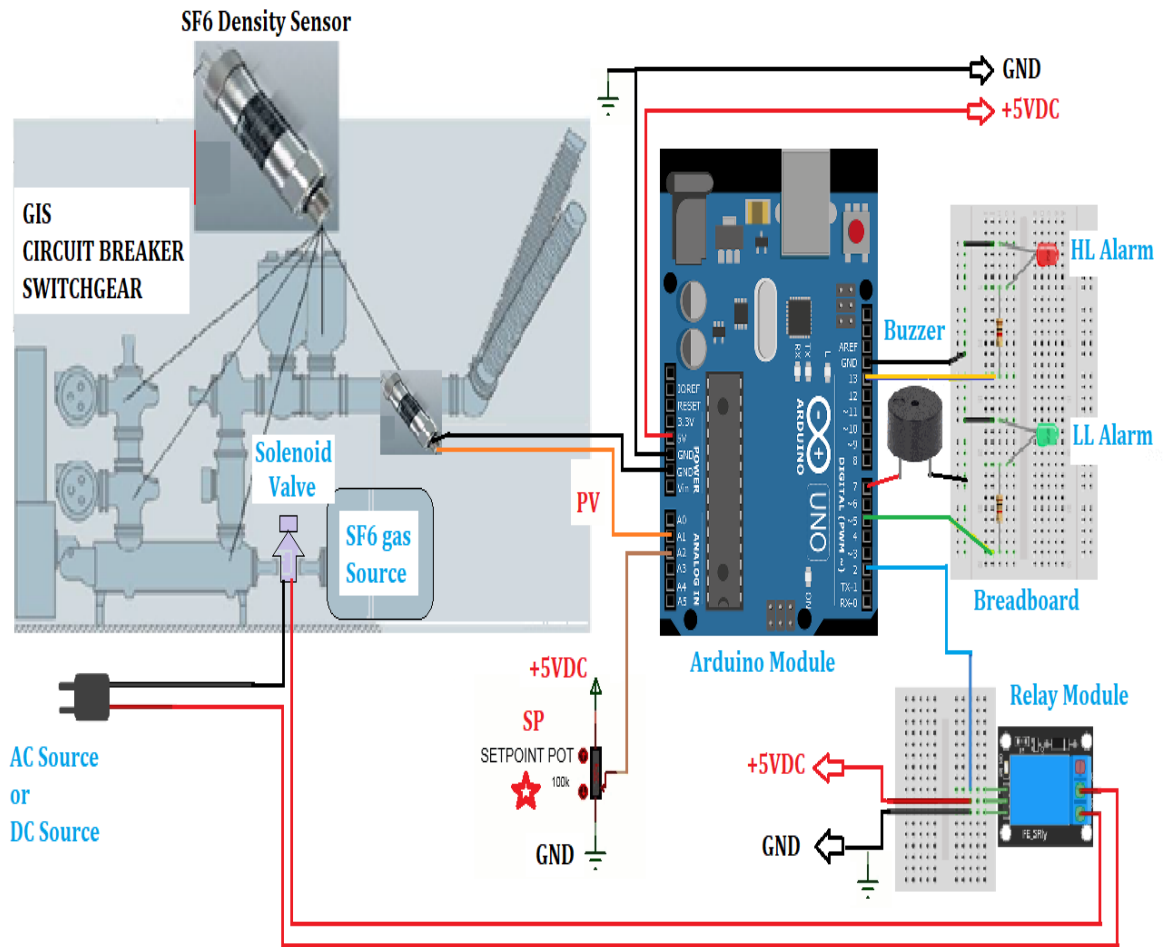
Figure 37. Arduino PID Monitoring and control system simulation

3.4.3. Designing LabView Program

In the field of monitoring and controlling, LabView software can be used for monitoring and controlling industrial systems. LabView is a natural instrument for obtaining load data when driving simulators or developing novel prototypes with mechanisms of necessary hardware operations due to its intrinsic input or output capabilities. Practical PID monitoring and control system design using LabView software consist of two parts:-

1-Front Panel Design:

As shown in Figure 38, the LabView program designs the program interface for monitoring and controlling the density and leakage of SF6 gas. It is designed as an interactive graphical interface to reflect the behavior of the industrial process to be monitored and controlled and the extent to which it achieves the desired control goal. The front panel contains numerical input elements for specific values , such as PID gain parameters, the desired value set point, and the limits of operating the upper HL and the lower LL alarm (Rajaraman, J et al,2014). The front panel also includes a graphical interface that is a secondary interface for displaying the system output response (Monitor Chart) and PV, SP, HL, and LL values.
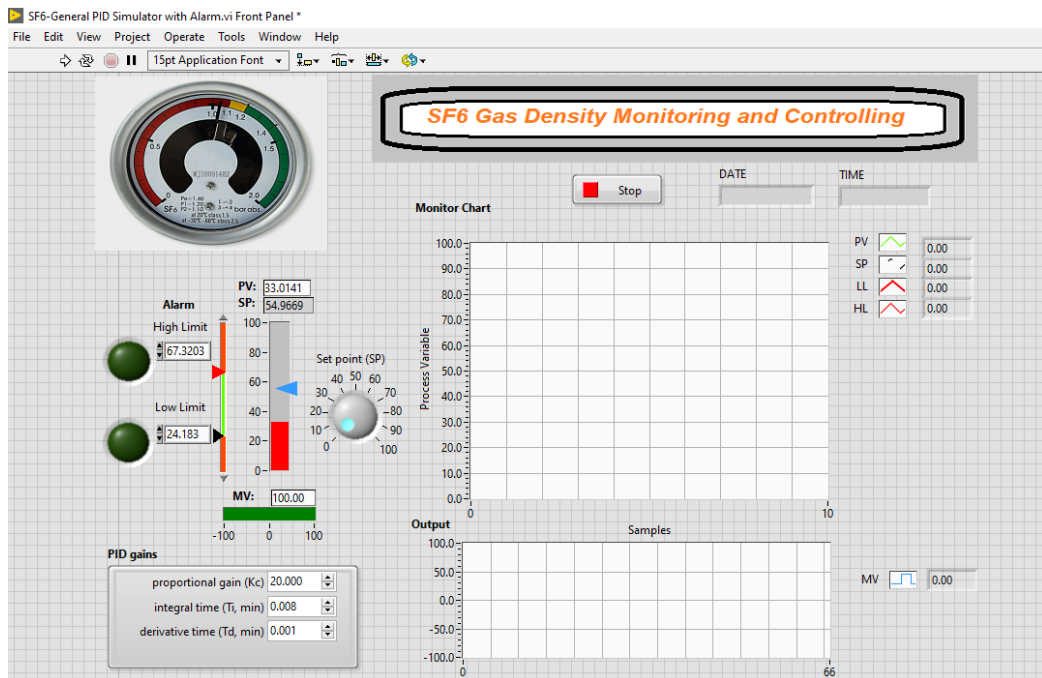

Figure 38 . Front Panel of SF6 Gas Density PID Controller Simulator with Alarm

2-Block Diagram Design:

The logical block diagram in Figure 39 represents the logical path to implement the PID system commands. It is an image of the reflection of the elements of the front panel of the LabView program in terms of entering the input parameter values of the industrial process and seeing how the control system interacts with them as an output response of the system(Kesavan et al,2014).
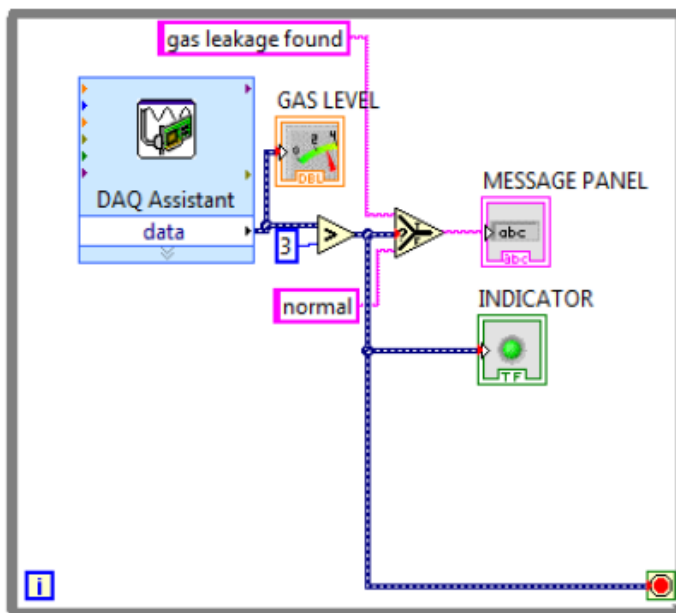

Figure 39. Block diagram example of LabView software

3.4.4. LabView Software System Design Work Principles

Refer to Figure 40; the SF6 gas monitoring and control system will be a participatory work between the two units of the front system and the logical block. The logical block is the executive support part of the path of instructions and the system's internal controls, starting from input to output (Rani et al,2014). The input here will be the value of the process variable, which represents the amount of SF6 gas density that is sensed by the SF6 gas density sensor inside the GIS equipment, from which a sample will be taken back fed to two logical comparison circuits (greater than or equal, less than or equal) in order to compare it with the desired value set point of the gas density. The outputs of the logical comparisons will stimulate the work of the alarm circuit by comparing any correct condition of the two states, either upper limit or lower limit, and it will appear as a red blinking indicator. At the same time, there are primary entries to the PID block unit, which are the PV value, SP values, PID, gains, and sampling time, which will be digitally controlled to guide and determine the behavior of the PID block for the desired industrial control, especially in conducting the test manual tuning process through a trial and error process to obtain the final values that achieve the best response output of the system.The output of the PID system with the values of PV, SP, HL, and LL will be entered into the monitor chart adjustment element block, which will display the response of these parameters in the form of an interactive time-varying graph on the front panel according to the values of the entered parameters and the values of setting the control of the system.
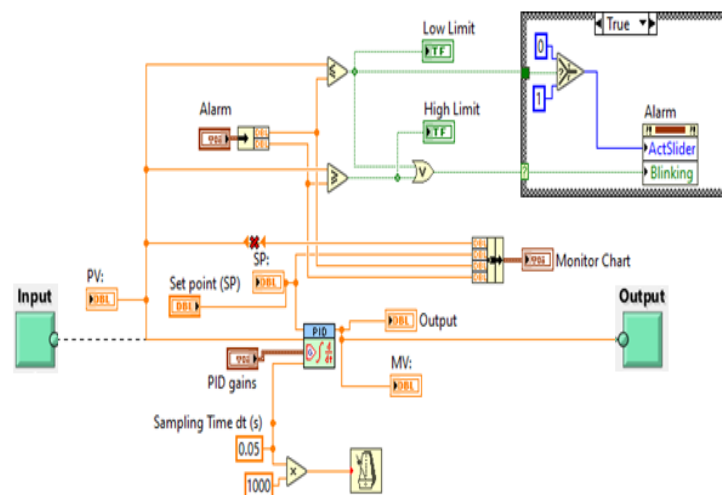

Figure 40 . Block diagram of SF6 gas density PID Controller simulator

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CHAPTER FOUR

# SF6 GAS MONITORING AND CONTROL SYSTEM DESIGN AND ANALYSIS

4.1. LabView Software System Design Types

 The Control Summary

A number of process variables, like temperature, are typically under your control in a control application. In a dynamic system, sensors detect the process variable and supply the data for the control application. The process variable's desired value is the set point. A comparator checks to see if the process parameter and the setting point vary. The compensator analyzes the data and decides the appropriate actuator output to move the system nearer to the setting point if a difference is there and the control system determines that it is significant enough.

The compensator analyzes the data and decides the appropriate actuator output to move the system nearer to the set point if a difference is there and the control system determines that it is significant enough. In measuring the temperature system, for instance, the compensator must operate to increase the temperature if the actual reading equals 100 °C and the setting point is 120 °C. Driving the heater with 62 per cent of its full capacity is an example of an actuator output. The system gets warmer as a result of the increasing heater actuator output, raising the temperature(Ali et al,2022) (Yu et al,2014).
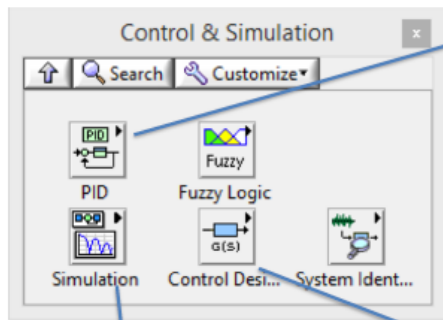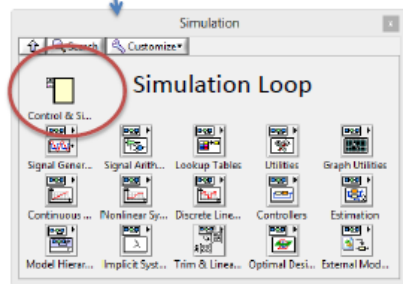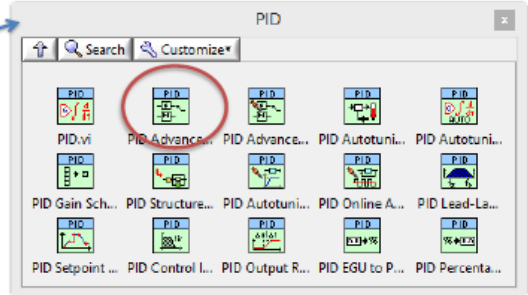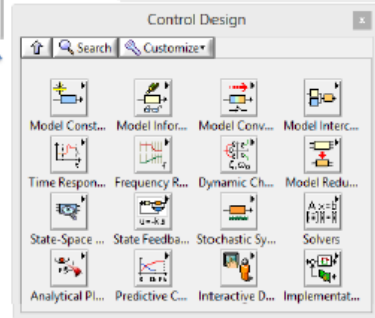
Figure 41 . LabView software abilities

4.1.1. Classic LabView Closed Loop System Simulation Design

This is a simplest method to represent any function by apply the following design steps for Control and Simulation in LabView:

1-Mathematical presentation

First, we need to represent the process with a mathematical relationship between the input variables and the output variable in order to find the output response of the control system.

For the example below of a certain industrial process, we need to design a LabView program to simulate a control process of a closed-loop system.

Let for a certain industrial process has the mathematical presentation:

x= - a x +b u

If we set: a = 0.25 and b = 9   , Where: 1/s represent an Integrator symbol.

2- Modeling of Dynamic System

This means that represent each term in the mathematical expression by a symbol and connect it with the program parameter.

Like: u: Input, b: Set point, a: feedback , and x:Output

3- Block Diagram design

The third step to design the control program is to draw the dynamic block diagram system according to the mathematical expression of the system.
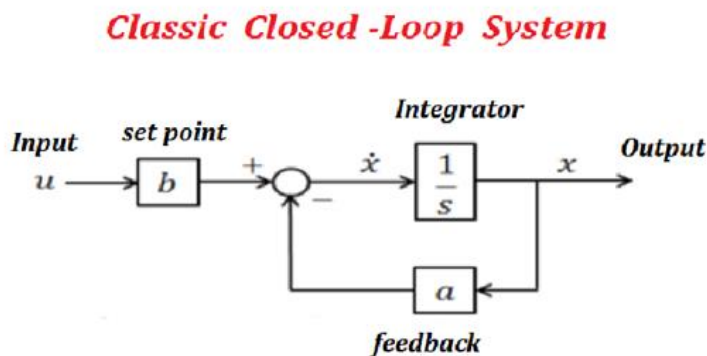
Figure 42 . Classic closed loop system example

4- Simulation in LabView

The last designing step is LabView program, First we need to create a new LabView program and choosing the front panel control elements such as input elements(such as fixed numerical cluster ,variable cluster), control elements(such as mathematical blocks, logical blocks, timing blocks, stop button…etc.) and output viewing elements(such as indicators and screen output chart).AS we know, the LabView program design consists of two parts which are:-

a) LabView Front Panel Simulation

Figure 43. LabView front panel classic closed loop system example

b) LabView Block Diagram Simulation

By select the suitable logic and mathematic blocks from the block diagram window, we will get the following design as shown in Figure 44.

Figure 44 . LabView block diagram classic closed loop system example

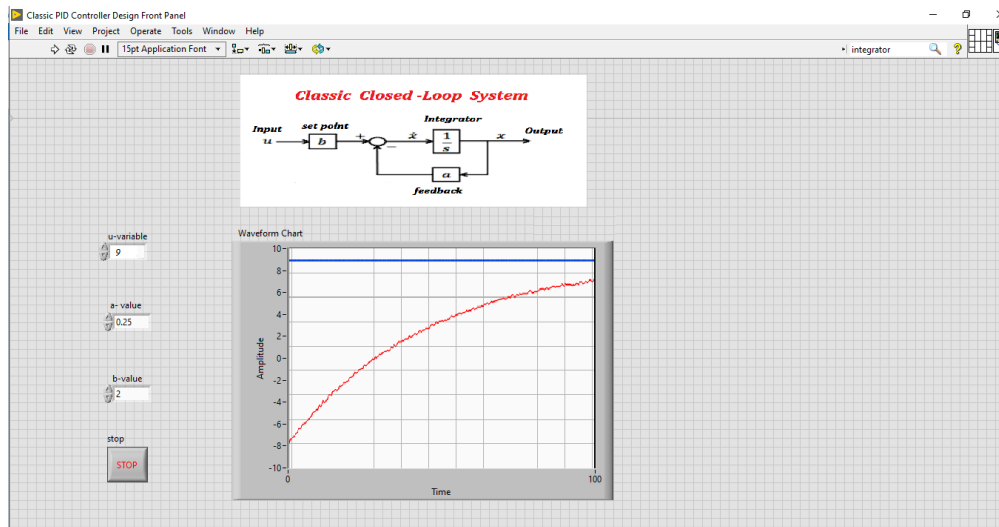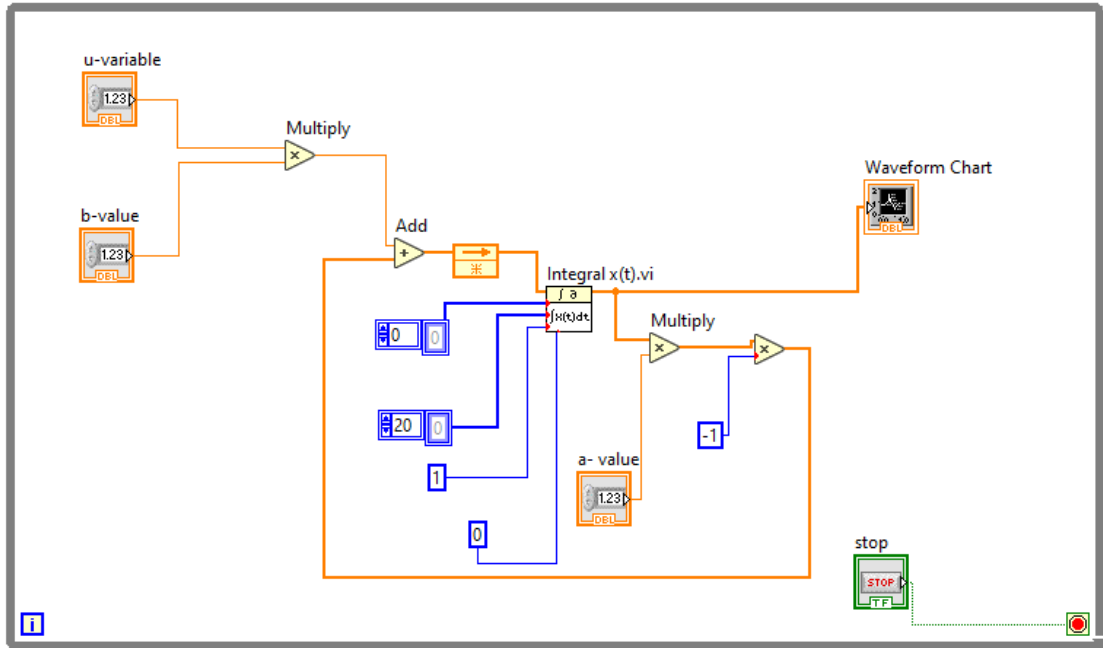### 4.1.2. LabView PID Palette Block System Simulation Design

When compared to the traditional procedure, this one is more precise and efficient especially when the process is more complicated and need more variables elements. LabView software presents a pre-programmed palette block diagram elements that be ready to use after some modifications according to the user requirements.
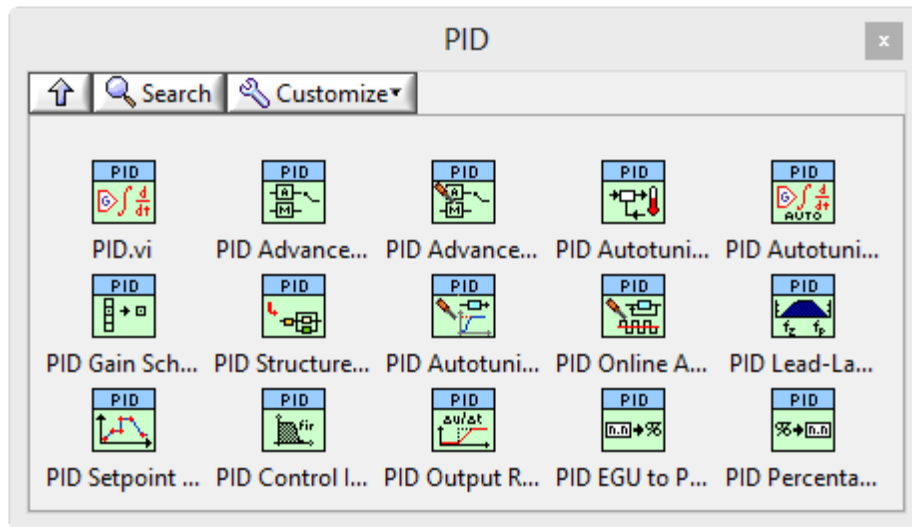
Figure 45 . LabView PID Palette Block types

Note that the functions (PID.vi) and (PID Advanced.vi) require that Ti and Td are in minutes while it's normal to use seconds as the unit for these parameters. This means we enter values for Ti and Td in seconds on the Front Panel and the values are converted to minutes in the code. As we learn before for LabView software that we built the front panel design and Block diagram logical design to get a complete simulation program according to the required function. As shown in the upper Figure 45, the PID palette offers many types of pre-programmed PID logical block which is surely suitable for different applications .

Figure 46 . LabView PID Palette Block System Simulation Design example

4.2. SF6 Gas DensityLabView Software System Design Work Principles

4.2.1. Manual-Tuning PID Controller Flow Chart Algorithm

Figure 47 illustrates a flowchart that contains the actual process and control components including sensors, valves, and measurement. This flowchart can be used to build a control strategy. We can also include process feedback samples and any calculations that are necessary. The 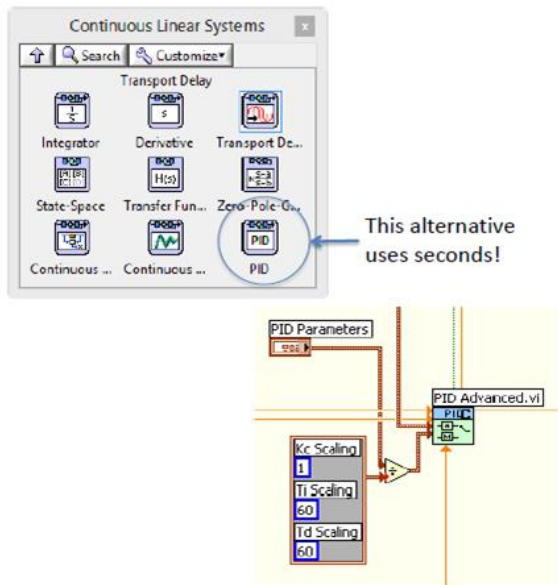flowchart can then be converted into a LabView diagram of blocks using the PID VI's (Virtual Instrumentation), math and logic VIs, and LabView functions.. This flowchart shows the flow of instructions inside the PID controller and how it deals with the input process parameter (PV) variation and is processed according to its value. The value of PV will be entered the system from gas density sensor while SP, K_P, K_I and K_d parameter values will be entered manually by the user. Hence E_{SS} value will be calculated and entered in the general output response PID equation. If PV equals or exceeds the limits of high limit (HL) or low limit (LL), then the corresponding suitable alarm will be blinking on the front panel of LabView software. The process will continue in sequence unless the user ends, until the minimum E_{SS}, minimum overshooting, and minimum settling time response are obtained. This means that the output response equals the set point desired approximately and satisfies the design and correct operation of the PID control system.
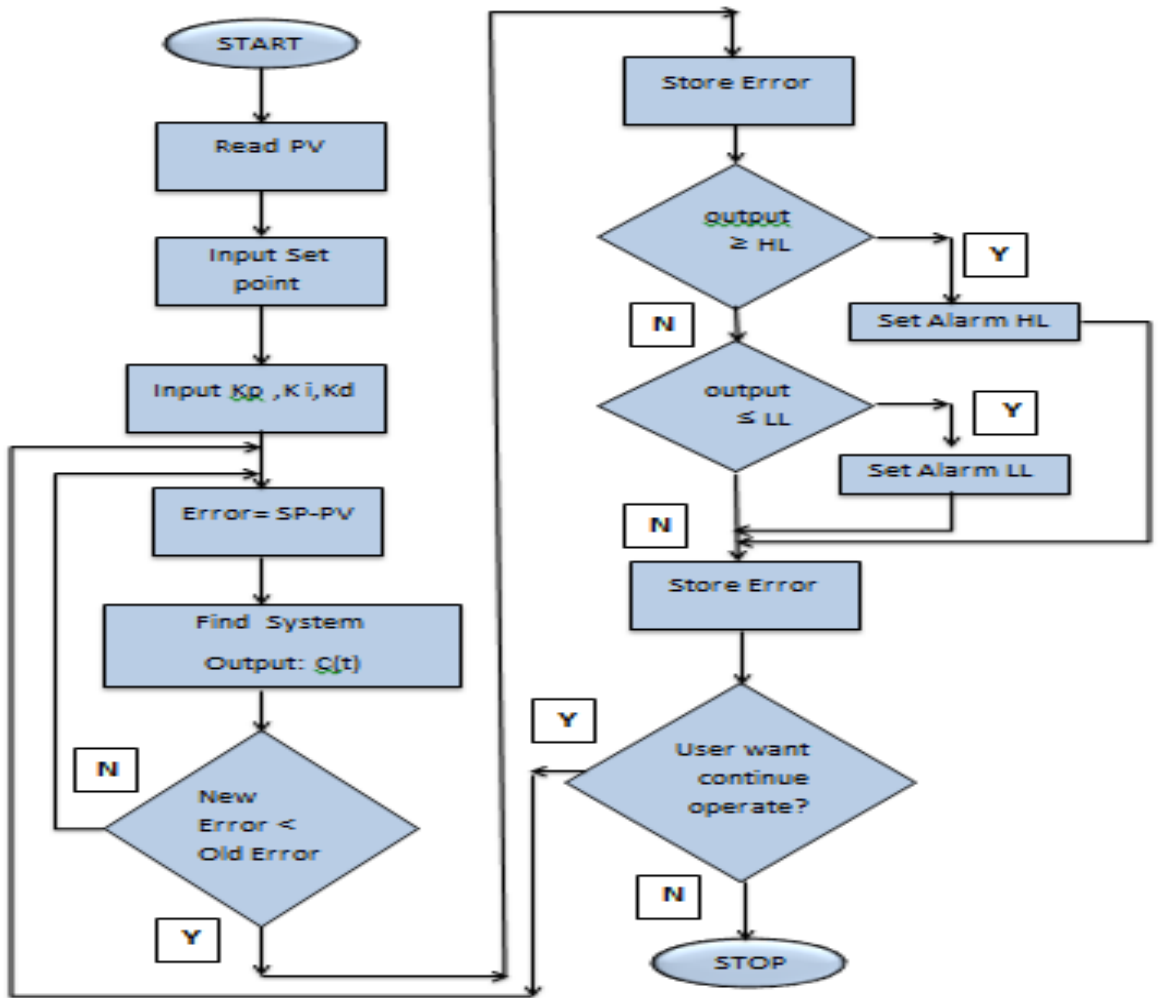
Figure 47 . Manual tuning PID system flowchart

4.2.2. Manual-Tuning PID Controller Flow Chart Work Principle

Manual tuning has been utilized with PID controllers to enhance system performance. The best PID parameters will be chosen through trial and error. This method is commonly used and is quite effective in industrial applications.. Many simulations using different P, I, and D values were necessary to create a visible system reaction. K_P, K_i, and K_d can all be specified in the setup section of the control system's code. The manual tuning steps can be repeated till we get the best output performance for the system which can be observed on the LabView program chart. For example, in the first test, K_i and K_d are set to 0, and K_p is set to a high value (K_p=10 for example). The constants are changed in response to the system output's behaviour shown on the chart displayed. Later, K_d might be raised manually, for instance, to lessen the severity of the negative overshoot [37-38]. The main steps of the experiments are as follows:

1. Adjust the initial PID controller parameters (K_p = high value, K_i = min. or zero value, and K_d = min. or zero value) and process variable set point.

2. Run the program and get the output response parameters and system trends.

3. Record K_p, K_i (or T_i), K_d (or T_d), PV, and steady-state error (E_{SS} offset value).

4. Repeat steps 1 to 3 with changing another gain parameter while fixing an old one, till you get the system's best output response of minimum overshoot, minimum steady state error, and minimum settling time. This operation in the real process takes a long time to complete after adding the PID controller and simulating the system in the real location to obtain the PID parameters due to several challenges, including the need for an instrumentation and control engineer with extensive experience working with online operating controllers and knowledge of reading and observing system responses when PID parameter values are changed. As a result, it is appropriate to replicate the PID system using open-source devices, techniques, and requirements for low-energy control applications such as Arduino applications. For clarity, Figure 48 shows an example of the system's response characteristics after the PID controller has been adjusted and how it responds to disturbances, such as changing the input feed by opening a solenoid valve value and monitoring the system's response to these changes.

The most crucial factors to take into account when analyzing a system's reaction are overshoot (O.S), rising time ((T_r), settling time (T_S), and E_{SS}. Based on these, a system's overall performance and results can be assessed.
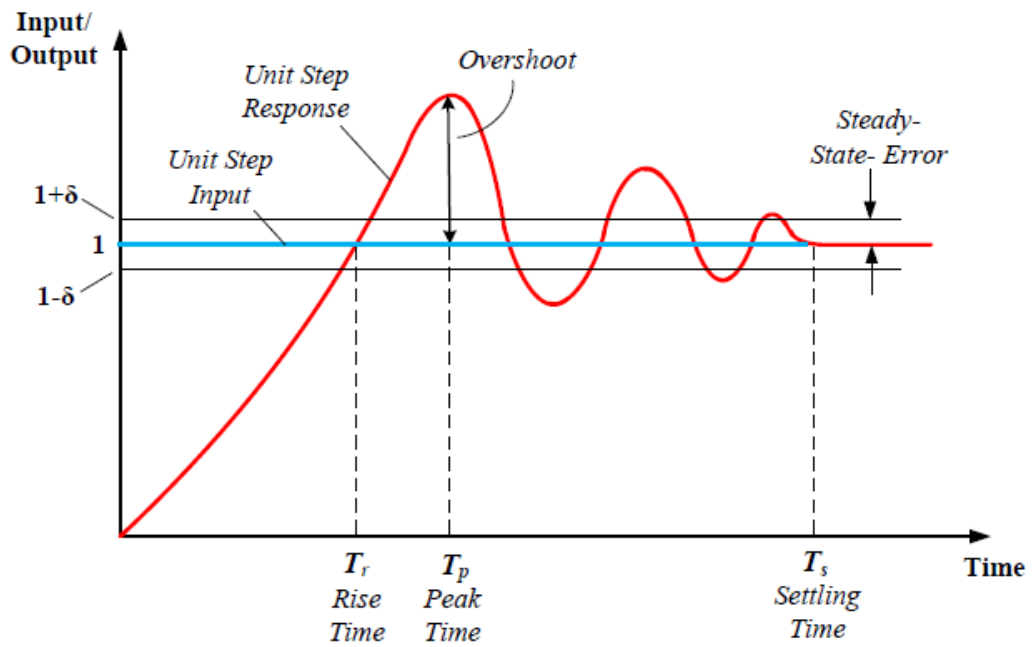
Figure 48 . Unit step input and output response example of a closed-loop system

4.3. LabView Auto-Tuning PID Controller Gain

4.3.1. Auto-Tuning PID Controller Flow Chart Algorithm

Designing a Control Strategy

Drawing a flowchart including the actual process and control components like valves and measurements will help you create a control plan. Include any necessary computations as well as the process's output feedback. You may then convert the flowchart to the LabView block structure using the PID VIs, together with LabView's logical and mathematical VIs and functions..The following flow chart algorithm Figure 49,shows an auto-tuning PID Controller design:

Figure 49 . Auto-tuning PID system flowchart

4.3.2. Auto-Tuning PID Controller Flow Chart Work Principle

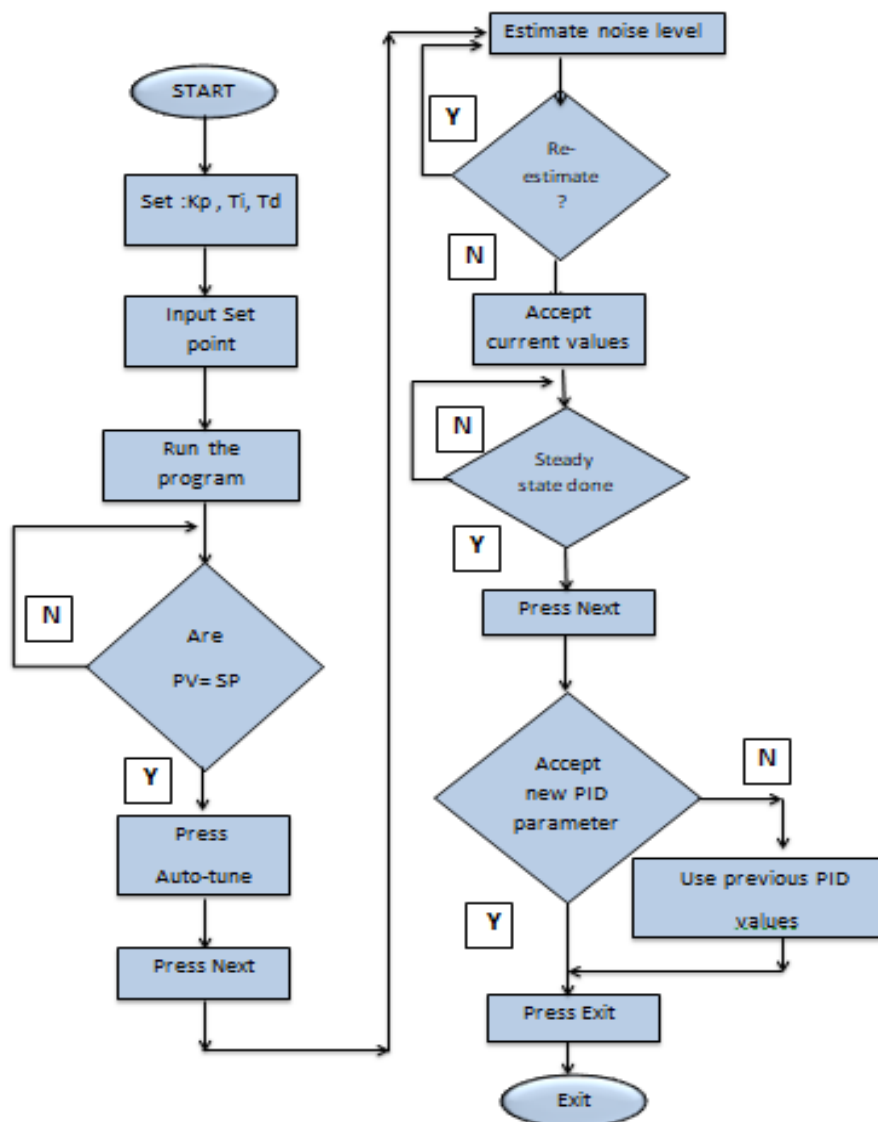The best values for P, I, and D can be obtained by tuning the controller. Criteria for tuning include things like a quarter decay ratio, a minimum settling time, a minimum overshoot error, and others. Process Reaction Curve is the most well-known empirical tuning technique, and it was created by Cohen and Coon. To determine the ideal value for parameters like P, I, and D from the process reaction curve, several tuning techniques including Cohen and Coon, Ziegle, and Nicholas Method are employed..The following example demonstrates how to simulate a simple control loop and a general plant model. This VI also demonstrates how you can use the PID Control VIs to auto-tune the PID gains.we can design an Auto-tuning PID closed loop system depending on the flow chart algorithm shown in previous Figure 49.Instructions for Auto-tuning PID closed loop system procedure:

1-Run the VI. When the PV value equals the SP value, click the Auto-tune button and   follow the steps of instructions in the PID Auto-tuning Wizard that appear during running the program.

2- To end the program, Click Stop button.
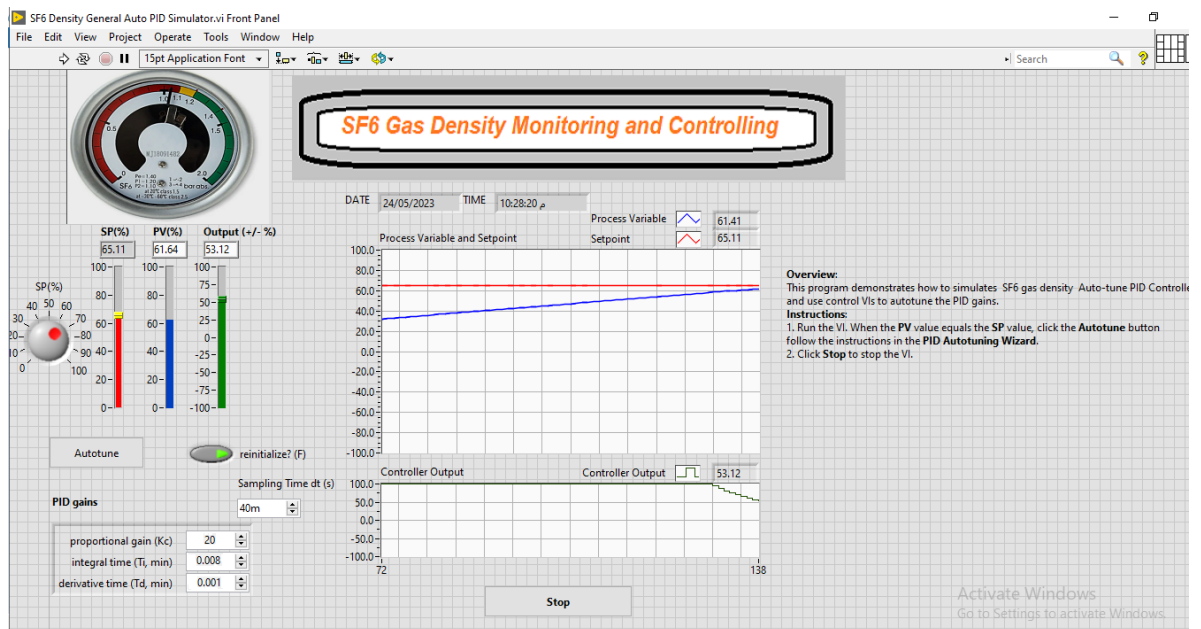
Figure   50 . LabView Auto-tuning PID System Simulation

Step 1 of 4: Set auto-tuning parameters

Edit the values this wizard uses for the auto-tuning process. Click the Next button to continue.
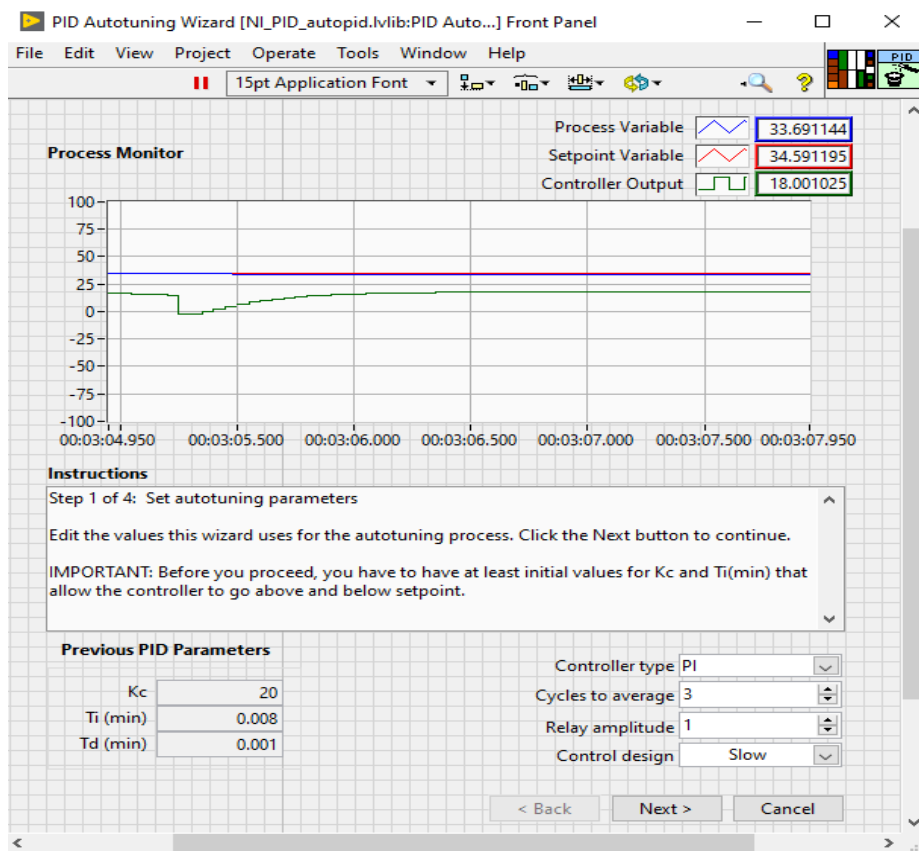
Figure 51 . LabView Auto-tuning PID System Simulation-step 1

IMPORTANT: Before you proceed, you have to have at least initial values for Kc and Ti(min) that allow the controller to go above and below set point.

Step 2 of 4: Estimate noise

This wizard uses the mean square noise level for the auto-tuning procedure. You can enter manually or calculate through the wizard.
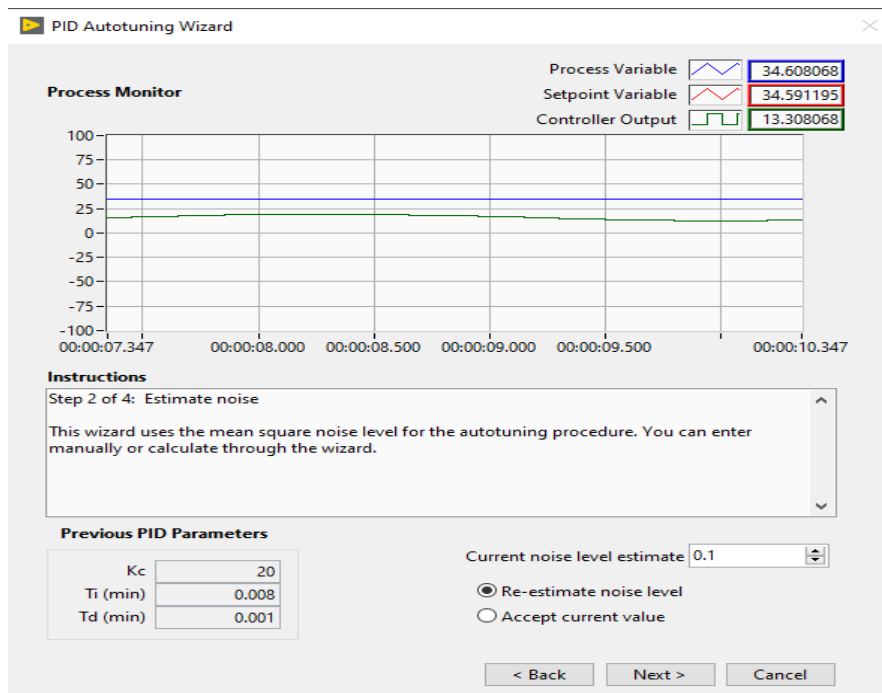
Figure 52 . LabView Auto-tuning PID System Simulation-step 2

Step 3 of 4: Set point relay

When you are sure the process is in steady-state or bounded oscillation, click the Next button to begin set point relay auto-tuning.

Figure 53. LabView Auto-tuning PID System Simulation-step 3

Step 4 of 4: New PID gains

This wizard has calculated the new PID parameters. You can accept or reject the values. If the new gains are accepted they will take effect immediately and fill PID box in front panel after Exit button is pressed.
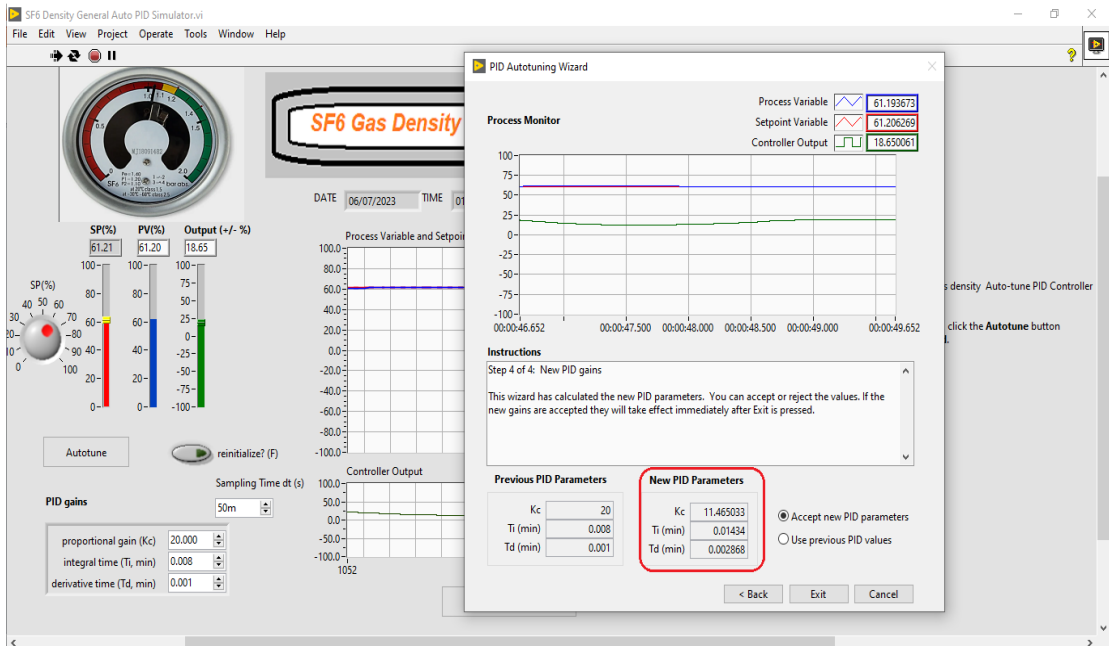
Figure 54 . LabView Auto-tuning PID System Simulation-step 4
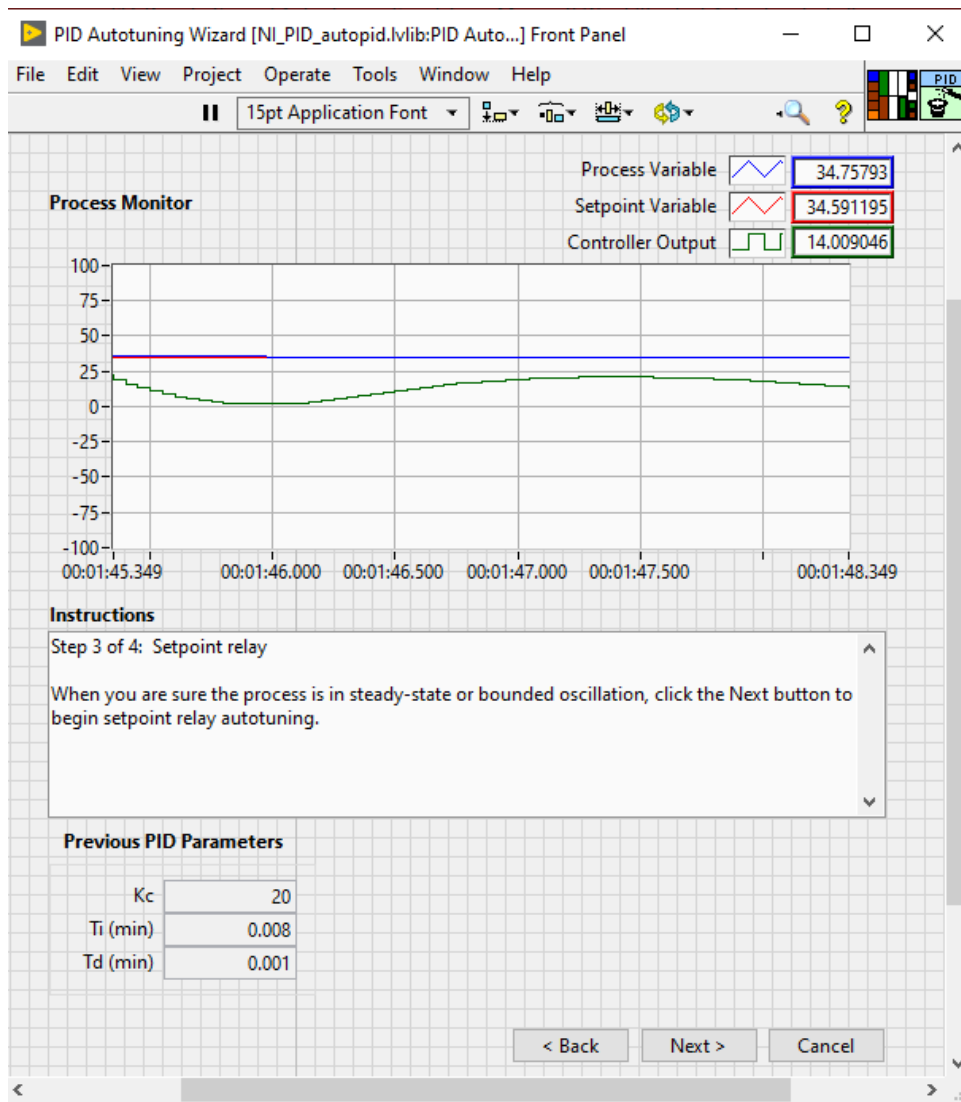
4.4. LabView Manual-Tuning PID Controller Steady Cases

4.4.1 Case 1: Change Only Proportrional Constant

For the first manual tuning study case, we will change the value of proportional constant value while fix the two other parameters of the PID controller gain.

$$K_p= \text{variable} \quad, T_i= 0.008 \quad, T_d= 0.001 \quad,\text{Set point}= 33.00 \text{ Kg/m}^3$$

Table 7 . LabView program output process response parameters for case study-1

Step Number	Density set point	K_p	T_i (s)	T_d (s)	PV	Rise time T_r (s)	Over Shoot	settling time T_s (s)	E_{SS} = SP - PV
1	33.00	5	0.008	0.001	38.5	0.35	5.5	23	0
2	33.00	10	0.008	0.001	35	0.35	3	21	0
3	33.00	15	0.008	0.001	34	0.35	1	19	0
4	33.00	20	0.008	0.001	33.5	0.35	0.5	17	0

The results in the Table above will shown in the next four figures below.

Figure 55 . LabView Manual-tuning output response for Case study1-1

Figure 56 . LabView Manual-tuning output response for Case study1- 2

Figure 57. LabView Manual-tuning output response parameters for Case study1- 3

Figure 58 . LabView Manual-tuning output response for Case study1- 4

4.4.2 Case 2: Change Only Integral Constant

In the second manual tuning study case, we will change the value of integration time constant value while fix the two other parameters of the PID controller gain.

$$K_p=10 \ , T_i= \text{variable} \ \ , T_d= \ 0.001 \ \ ,\text{Set point}= 33.00 \ \text{Kg/m}^3$$

Table 8 . LabView program output process response for case study-2

Step Number	Density set point	K_p	T_i (s)	T_d (s)	PV	Rise time T_r (s)	Over Shoot	settling time T_s (s)	E_{SS} = SP - PV
1	33.00	10	0	0.001	28.95	0.35	0	∞	- 4.05
2	33.00	10	0.1	0.001	31.42	0.35	0	∞	- 1.58
3	33.00	10	0.2	0.001	33.02	0.35	0	∞	None
4	33.00	10	0.3	0.001	33.05	0.35	0	∞	None

The results of the second case study in the Table above will shown in the next four figures below.
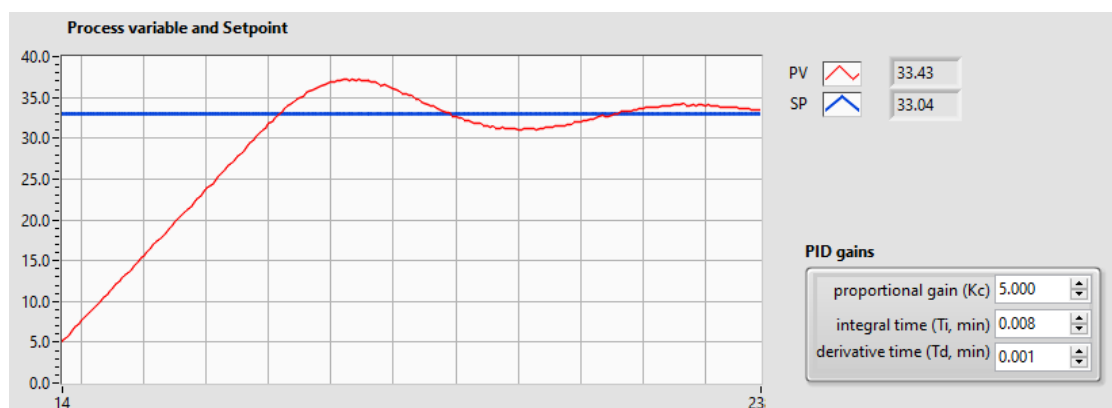
Figure 59 . LabView Manual-tuning output response for Case study2- 1

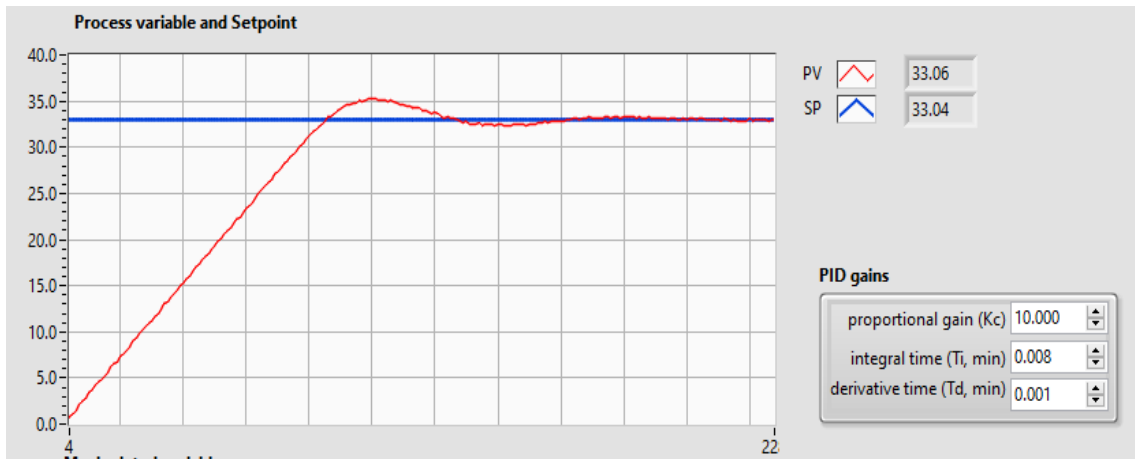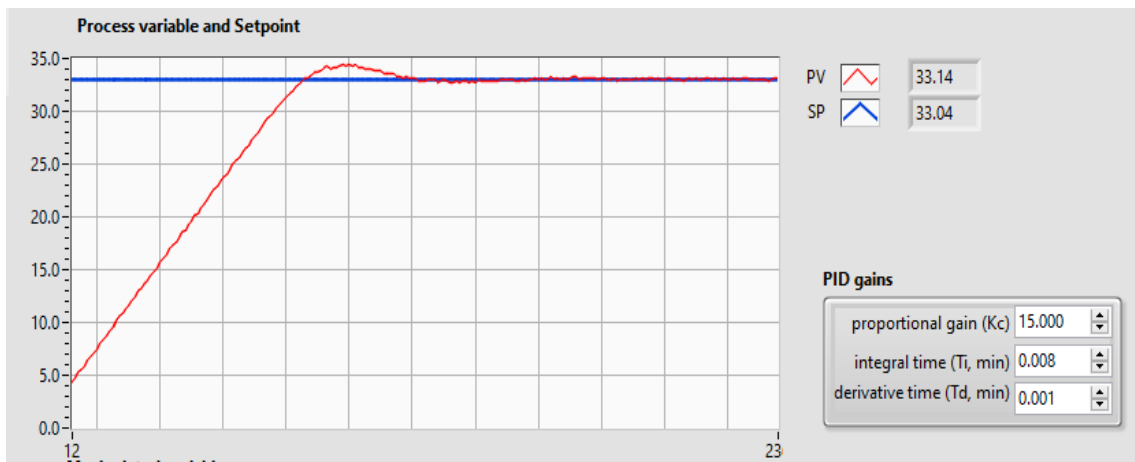**Figure   60 .** LabView Manual-tuning output response for Case study2- 2

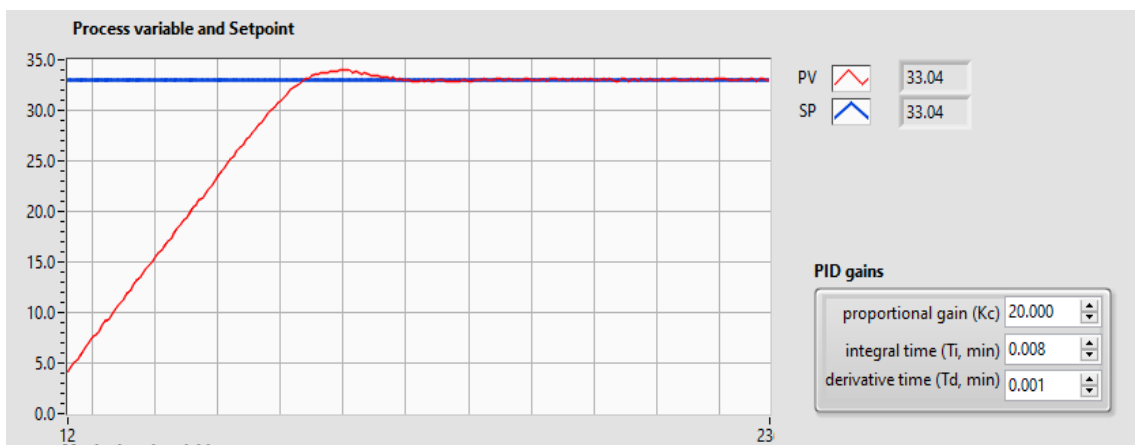**Figure 61 .** LabView Manual-tuning output response for Case study2- 3

Figure 62 . LabView Manual-tuning output response for Case study2- 4

4.4.3 Case 3: Change Only differential Constant

In the third manual tuning study case, we will change the value of diffrentiation time constant value while fix the two other parameters of the PID controller gain.

$$K_p=10 \ , T_i= 0.1 \quad , T_d= variable \quad ,Set \ point= 33.00 \ Kg/m^3$$

Table 9 . LabView program output process response parameters for case study-3

Step Number	Density set point	K_p	T_i (s)	T_d (s)	PV	Rise time T_r (s)	Over Shoot	settling time T_s (s)	$E_{SS} =$ SP - PV
1	33.00	10	0.1	0.001	33.8	417	0.8	58	- 0.8
2	33.00	10	0.1	0.001	34.8	365	1.8	54	- 1.8
3	33.00	10	0.1	0.001	- 571.69	0.35	0	∞	604.69
4	33.00	10	0.1	0.001	- 350.97	0.35	0	∞	381.97

The results of the third case study in the Table above will shown in the next four figures below.
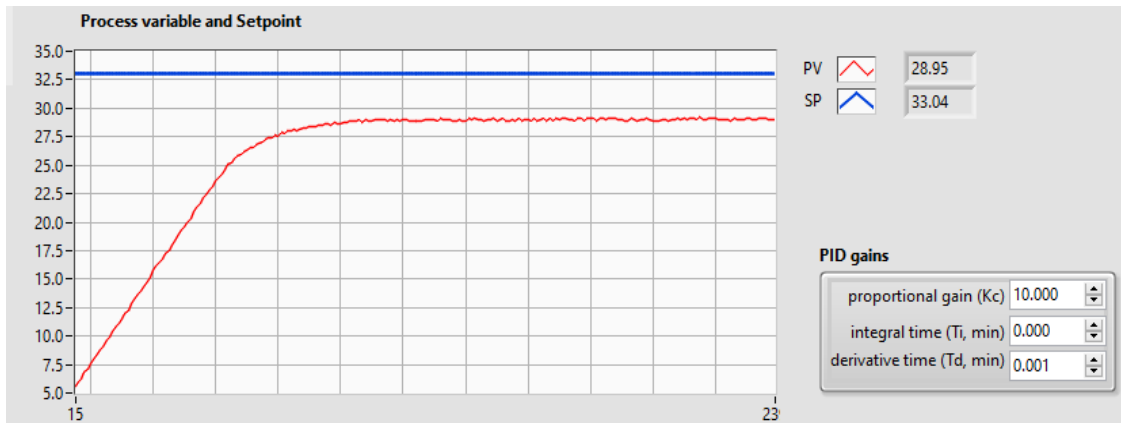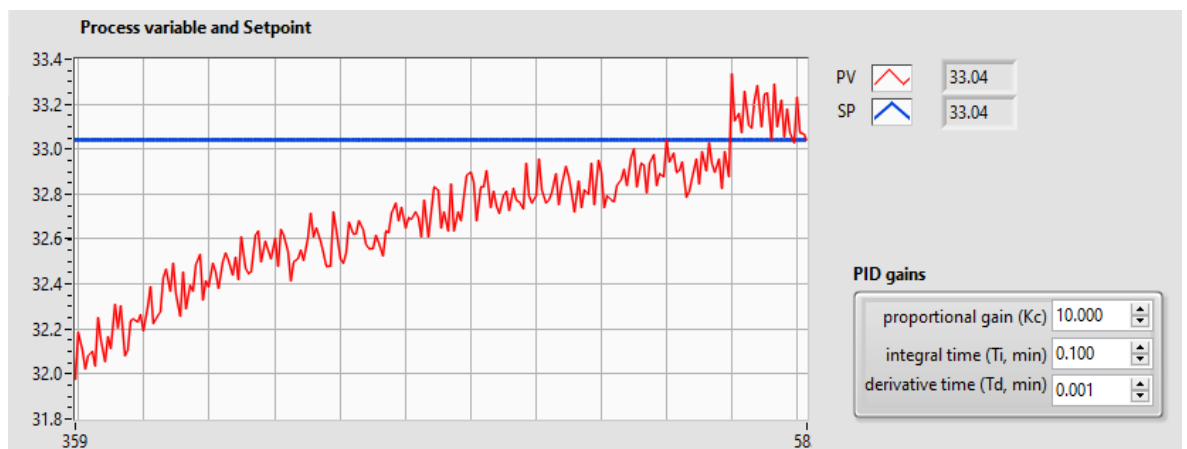

Figure 63 . LabView Manual-tuning output response for Case study3- 1
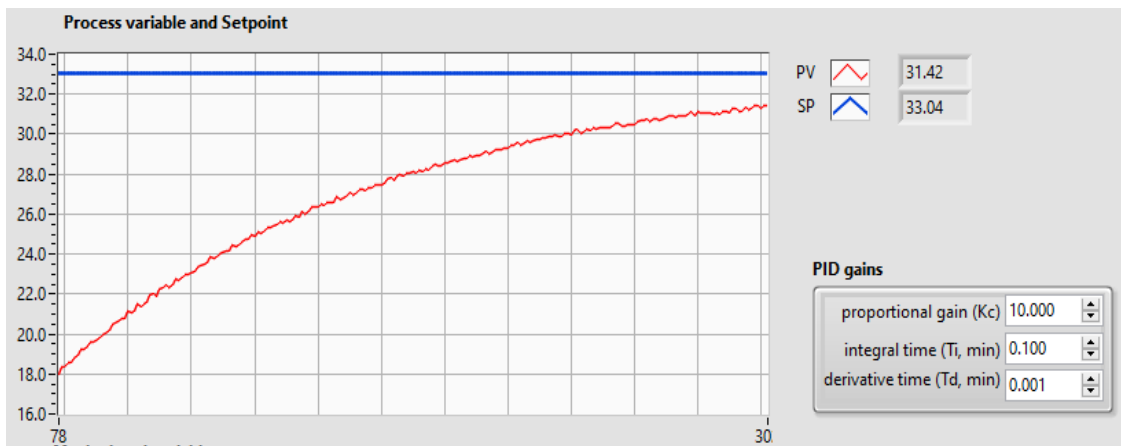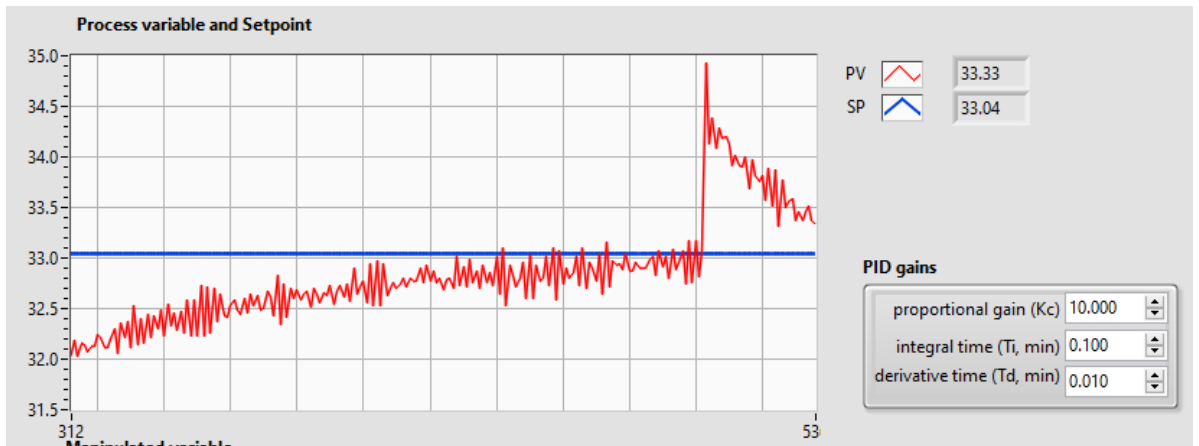
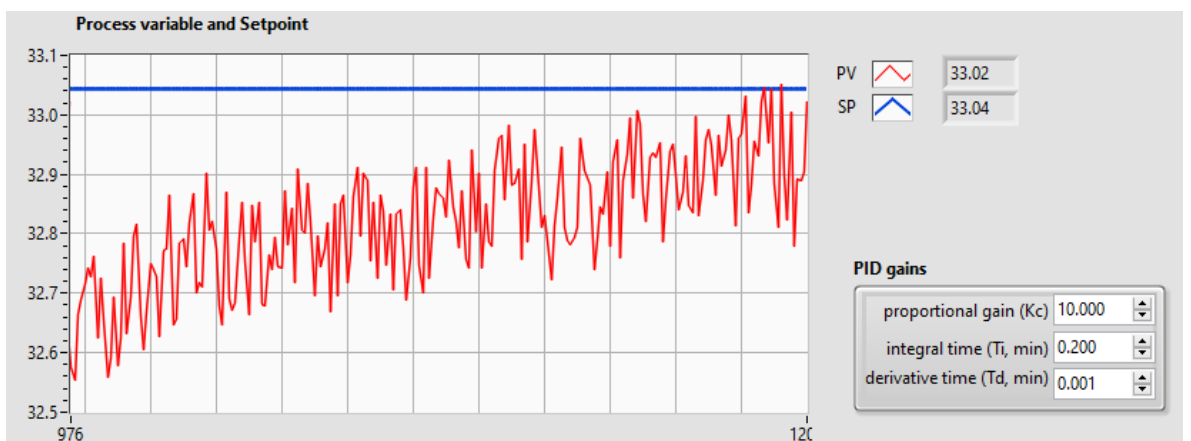**Figure 64 .** LabView Manual-tuning output response for Case study3- 2

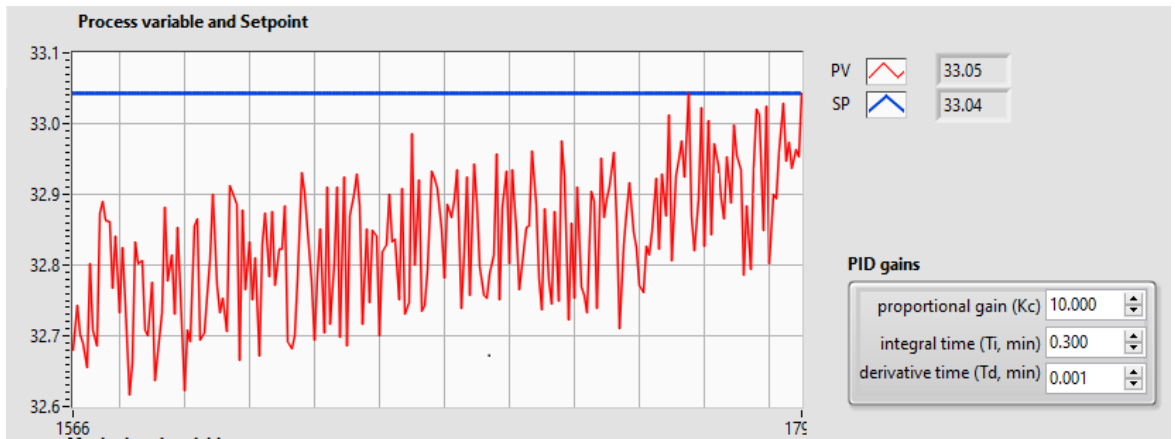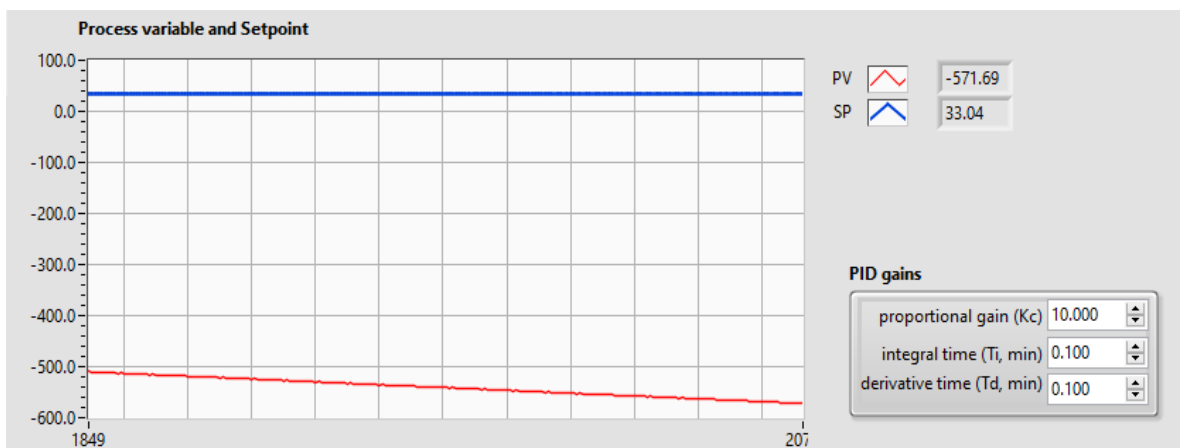**Figure 65 .** LabView Manual-tuning output response for Case study3- 3
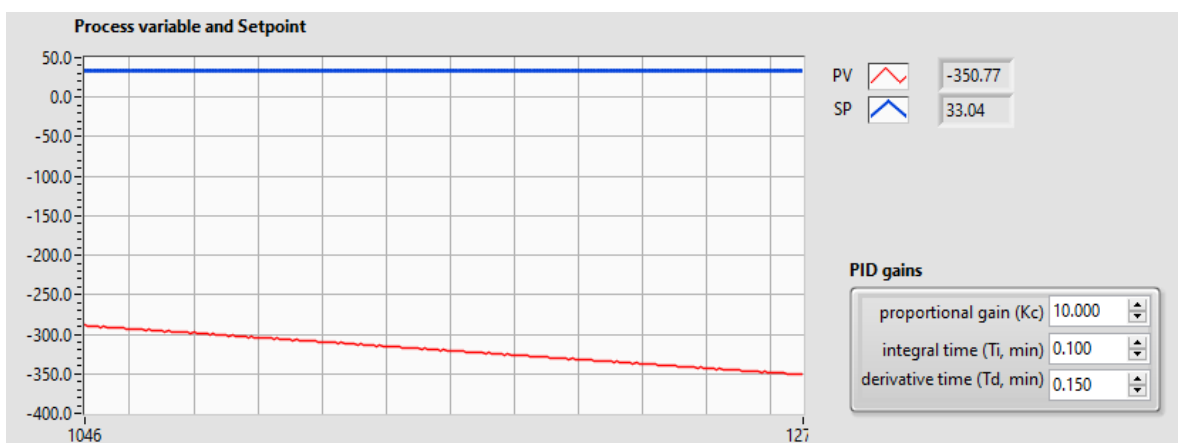
Figure 66 . LabView Manual-tuning output response for Case study3- 4

4.5. Results Analysis and Discussion

4.5.1 Results from Manual Tuning PID System

The output response of the proposed PID system designed by LabView software can be shown in Figure 67. Using PID gain levels, the waveform chart illustrates the process's output response. The PV value will vary continuously during the execution of the monitoring and control program to indicate the process of SF6 gas density. Any gas leakage in the GIS equipment will affect the total gas density, which the system will sense. Also, suppose there is any extended case for the physical gas property by the temperature that may occur by continuous GIS switching circuit breakers or other equipment. In that case, this gas density change will either exceed the upper limit or decrease the lower limit, which makes the system start an alarm blinking signal and an alarming buzzer to inform the responsible monitoring person about the GIS substation system state.
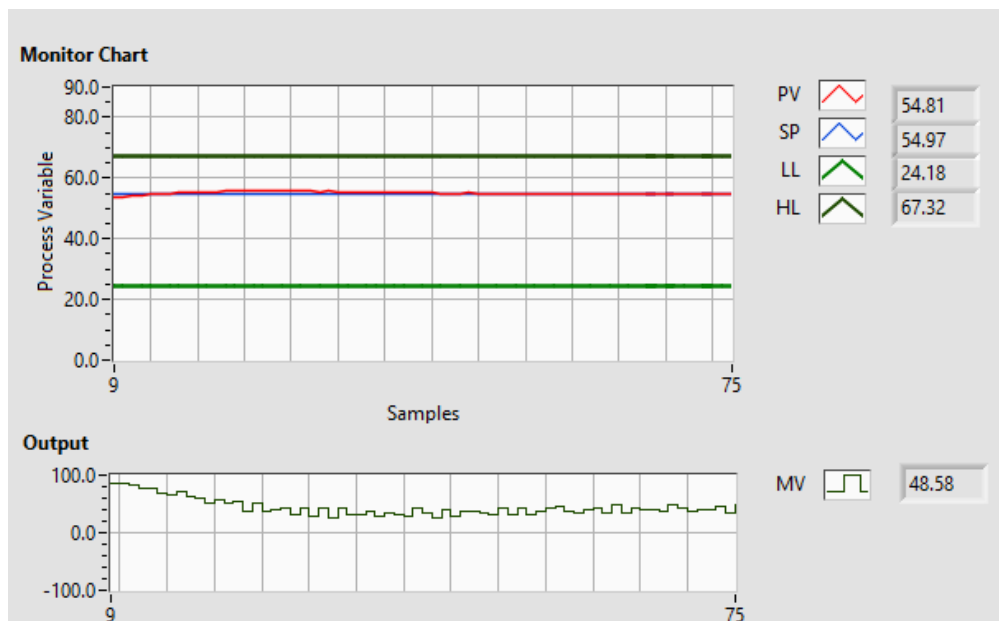
Figure 67 . Monitoring and control LabView program output process response

Table 10. below shows that the PID manual tuning parameters range is refined during the manual tuning. In order to help the controller initially provide enough value to reach the set point K_P is sufficiently raised. An initial oscillation is produced before entered K_i and K_d to get stable output.

Table 10 .PID manual tuning parameters range of PID control system response

Parameter	Changing Range
SP	0 → 100
K_p	0 → 30
T_d (s)	0 → 1
T_i (s)	0 → 1

These variables aid in developing an adequate gas density amount control system using Arduino and PID control. The ability to save processing time by removing polling loops in the code is another benefit of the capability offered by microcontrollers like Arduino. Interrupt systems are used by Arduino, either externally or through code. This enables the processor to execute the code's main loop until one of the interrupts notifies the Arduino when a specific event occurs. This increases the process's overall response time, further suggesting the potential of open-source instrumentation design. Before analyzing the output system performance, first, it needs to find the appropriate parameters of K_P, K_i and K_d of PID controller within the parameter ranges shown in Table 10. For this purpose, a trial-and-error method is used to obtain the best time response and satisfies a particular criterion. We will examine the effects of our system design by three case studies in order to get the best PID parameters results when changing one of these parameters in each case, and notice the output response behavior and how much it improves the system. The next step will enter these values in the Arduino card sketch file's programming code to stand alone PID system operation to maintain the desired gas density set point. Figure 68 below shows the front panel of LabView software when applying the three study cases, PID gain values, set point knob, indicator alarms, and output response curves.
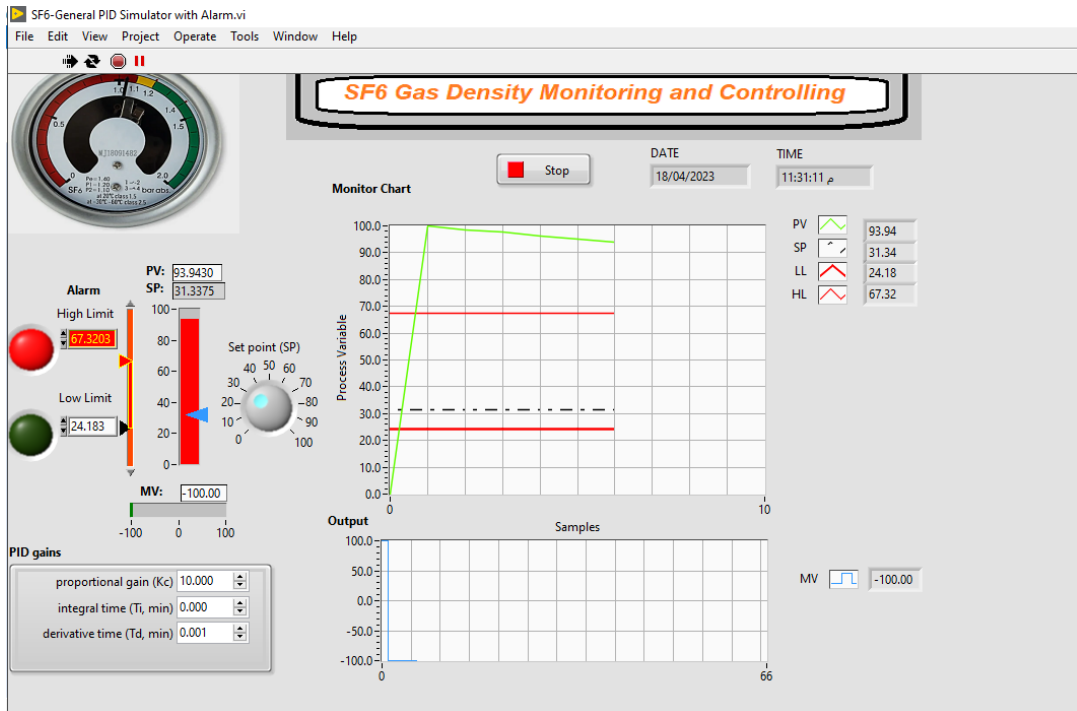
Figure 68 . LabView front panel system output response.

Disscussion:

1-For case study 1 (we change only proportional constant). Particularly, we manually set the PID controller parameters as follow: $K_p \in \{5,10,15,20\}$, $T_i = 0.008$, $T_d = 0.001$ and Set point = 33 Kg/m3. The measured process density value inside GIS equipment is varied. The main idea of this case is to study the effect of a significant value of K_p on the system response when it decreases other parameters. So, we start with ascending K_p value and minimum values for T_i, and T_d. The study case 1 included four sub-cases to change the value of the proportional constant ascending. The system's output response was a fast rise time with a decrease in the overshoot value in each subsequent secondary case, and the value of the process value was equal to the desired set point value which produces the minimum or zero steady state error and fastest settling time as shown in case 1-4.

2-For case study 2 (change only Integral time constant), we manually set the PID controller parameters as follow: $K_p = 10$, $T_i \in \{0,0.1,0.2,0.3\}$, , $T_d = 0.001$ and Set point = 33 Kg/m3. For this case, we want to study the effect of increasing the value of T_i and see how it can change the value of overall shooting response and

minimize the oscillation results or not in case study1 of large K_p value. In the study case 2, the value of the integration time was changed upward through four sub-cases, with fixed values of the proportional gain and the derivative time. The system's rise time was relatively slower than that of study case 1. It was noted here that increasing the integration time value makes the output system response became unstable (oscillation) and The process value did not reach the desired set point value, so, with increasing the value of integration time, will increase the instability of the system.

3-For case study 3 (Change only derivative time constant), we manually set the PID controller parameters as follow: $K_p =$ 10, $T_i =$ 0.1, $T_d \in \{0.001, 0.01, 0.1, 0.15\}$, and Set point = 33 Kg/m3. Her, we aim to study the effect of increasing a T_d value with previous cases K_p and T_i values and see how the system output response will be. As shown for the study Case 3, the derivation time value was shifted upward by four sub-cases, with constant values for the relative gain and the integrated time. The system rise time was the slowest compared to the previous two study cases 1 and 2. It was observed here that increasing the value of the derivative time makes the response of the output system unstable (oscillation) and the value of the process value for the sub-cases 3-3 and 3-4 did not reach the required set point value but continued with negative values moving away from the required set value, therefore, with an increase in the value of the derivative time, will increase system instability.

4.5.2 Results from Auto -Tuning PID System

An auto-tuning PID system almost designed using the Zeigler-Nichols method where a program of autotune starts an automatic tuning routine . This routine attempts to find the best values for P, I, and D using ultimate gain method. Upon completion, the new PID values are automatically entered into the control box.we simplify using the software by apply a procedure of four steps. First set point value and the PID values can be set in a numerical control box manually.

Table 11 . Auto-tuning results comparision

Tuning Type	Kp	Ti(sec)	Td(sec)	Tr(sec)	Ts(sec)	Max. Overshoot%	Stability
Auto	11.46	0.014	0.002	50	110	45.67	better
Auto-ref.3	20.533	6.749	1.684	112	225	82.7	better

As shown in the Table 11 , the comparison between the PID results of our Auto tuning, and Auto tuning results of ref.3 of the title (Evaluation of PID tuning methods on direct gas fired oven). We found that our Auto tuning method gain results are better than ref.3 results to reach the system stability for the same 2nd order closed loop systems design algorithm of Ziegler-Nichols method. That means satisfy the objectives of:

a) Stable control system output response.

b) Minimum over shoot values.

c) Minimum settling time.

d) Minimum steady state error.

So,the advantages of an auto-tuning method to get PID gain parameters compared with manual tuning method are:-

1-More accurate to get final gain parameters.

2-Faster than manual method.

3- Offer new PID gain parameters in the end of runing program procedures which almost represent the best actual values

4-Offers estimation of noise level .

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1   Conclusions

This thesis presented a design of SF6 gas leakage monitoring and controlling PID system of GIS high voltage equipment based on LabView software which offers a flexible using, where the system was designed according to the Algorithms of desired instruction sequence of the PID processing for LabView software.Different parameters such as over-shooting, oscillation, settling time, and steady-state error was considered to evaluate the system design.In order to get evaluate the system performance , three manual tuning study cases scenarios have been considered a different PID parameters where the case1-4 shows that the large value of the proportional constant with small values of the other two gain parameters will decrease the overshooting and oscillation and make the fast settling time for steady-state response.Also, another LabView design for Auto-Tuning PID system was presented and simulates to get the system's output response where it designed according to Ziegler Nichols method which showed the better and faster method than manual tuning method to get the stable response and PID gain values of the system. Compared Auto-tuning results with the previous study and research objectives, we've got the system satisfy the main objectives of:

Stable control system output response, minimum over shoot values, minimum settling time and minimum steady state error.

5.2 Recommendations

 For future work, this study can be developed as follows:-

1- Apply the system with high rated power control industrial equipment controllers and field actuators to complete industrial automated systems.

 2-The system can comprise a remote automated system with industrial communication wired or wireless networks of any technique.

3- The system can be develope by take into account the delay time in a PID network and study its effect between transmitting and receiving process parameters.

4. It may design and implement the PID control system depending on Fuuzy Principles according to the real requirement of industrial system.

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