EC5030 - DESIGN PROJECT

IMPLEMENTATION OF PID CONTROLLER

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SEMESTER 5

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Voltage follower

A voltage follower (also known as a buffer amplifier, unity-gain amplifier, or isolation amplifier) is an op-amp circuit whose output voltage is equal to the input voltage (it "follows" the input voltage).

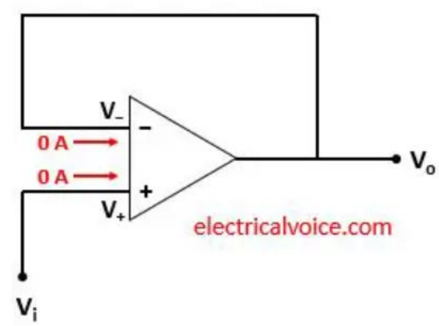
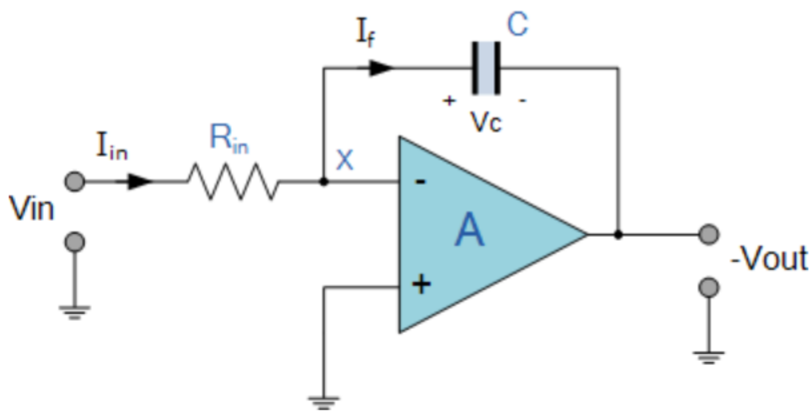


Fig. 2 voltage follower circuit analysis

Op amp integrator



Op-amp Integrator Circuit

$$V_c = \frac{Q}{C}$$

$$V_c = V_x - V_{out} = 0 - V_{out}$$

$$-\frac{dV_{out}}{dt} = \frac{dQ}{C\,dt} = \frac{1}{C}\frac{dQ}{dt}$$

$$I_{in} = \frac{V_{in} - 0}{R_{in}} = \frac{V_{in}}{R_{in}}$$

The current ~~follow~~ flowing through the feedback capacitor C

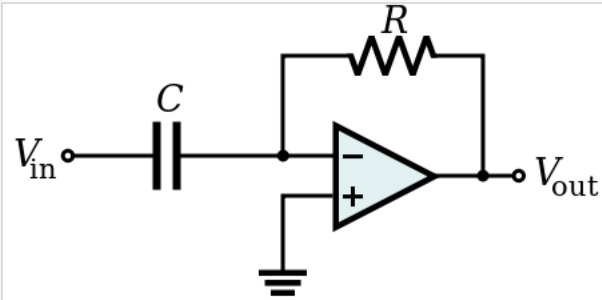
$$I_f = C\frac{dV_{out}}{dt} = C\frac{dQ}{C\,dt} = \frac{dQ}{dt}$$

$$I_{in} = I_f = \frac{dQ}{dt} = \frac{d\,V_{out}C}{dt}$$

$$\frac{V_{in}}{V_{out}} \times \frac{dt}{R_{in}C} = 1 \Rightarrow V_{out} = -\int_0^t V_{in}\frac{dt}{R_{in}C}$$

$$= -\frac{1}{j\omega RC}V_{in}$$

Ideal Differentiator



Ideal differentiator.

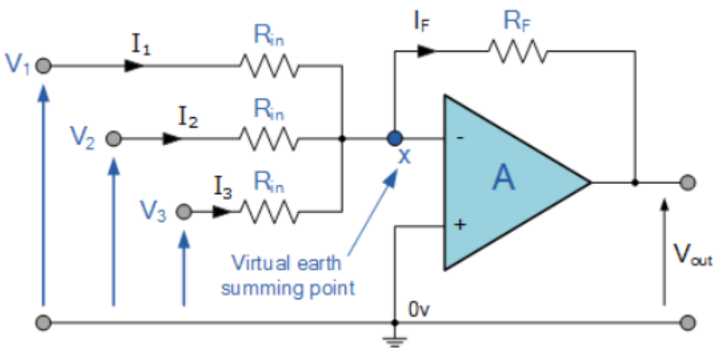
Differentiator

$$I = C \frac{dV_{in}}{dt}$$

$$V_{out} = -IR$$

$$= -R \cdot C \cdot \frac{dV_{in}}{dt}$$

<u>Summing Amplifiers</u>



<u>Summing Amplifier</u>

$$I_F = I_1 + I_2 + I_3 = -\left[\frac{V_1}{R_{in}} + \frac{V_2}{R_{in}} + \frac{V_3}{R_{in}}\right]$$

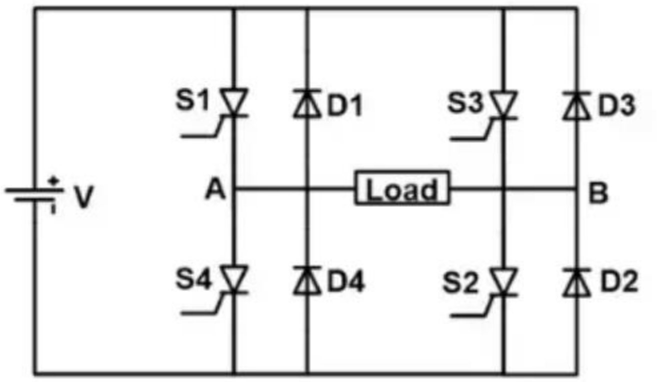
Inverting Equation

$$V_{out} = -\frac{R_f}{R_{in}} \times V_{in}$$

$$\therefore -V_{out} = \left[\frac{R_f}{R_{in}} V_{in} + \frac{R_f}{R_{in}} V_2 + \frac{R_f}{R_{in}} V_3\right]$$

$$\therefore -V_{out} = \frac{R_f}{R_{in}} \left[V_{in} + V_2 + V_3 + \dots \text{etc}\right]$$

Inverter

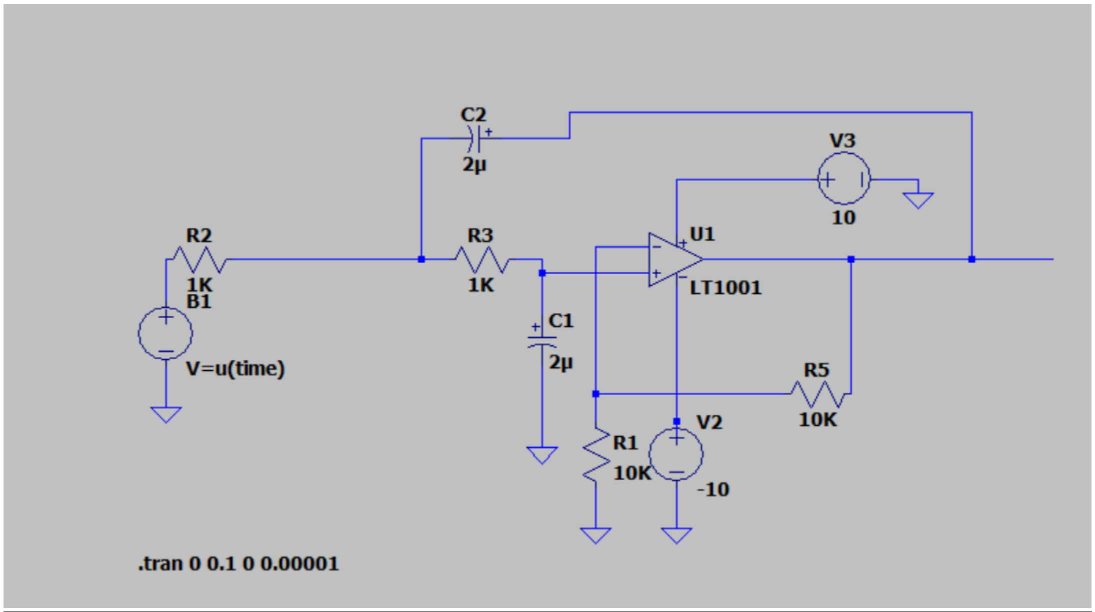


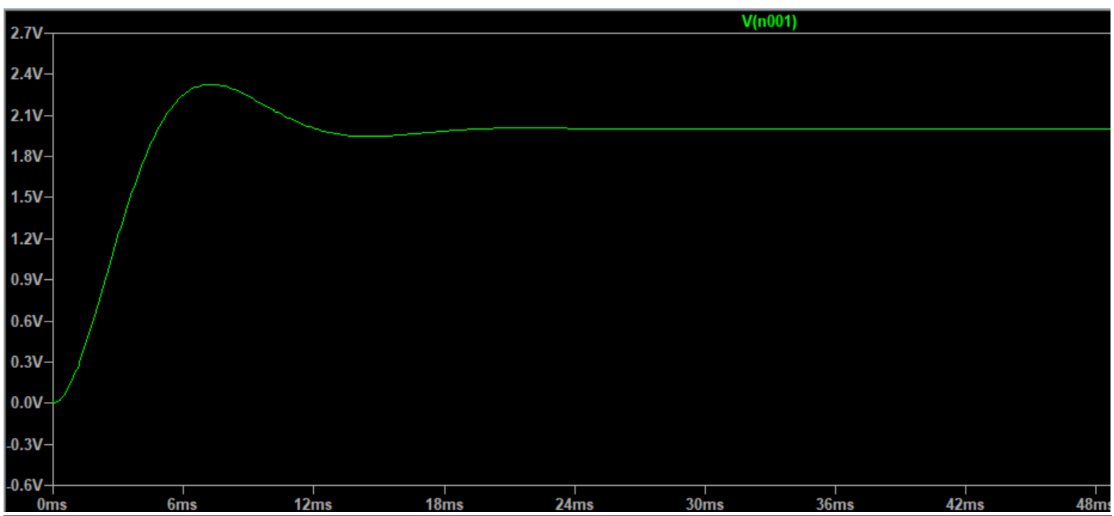
An inverter (or power inverter) is a power electronics device which used to convert DC voltage into AC voltage. Although DC power is used in small electrical gadgets, most household equipment runs on AC power.

Hence we need an efficient way to convert DC power into AC power.
The inverter is a static device. It can convert one form of electrical power into other forms of electrical power. But it cannot generate electrical power. Hence the inverter is a converter, not a generator.

It can be used as a standalone device such as solar power or back power for home appliances. The inverter takes DC power from the batteries and converts into AC power at the time of the power failure.

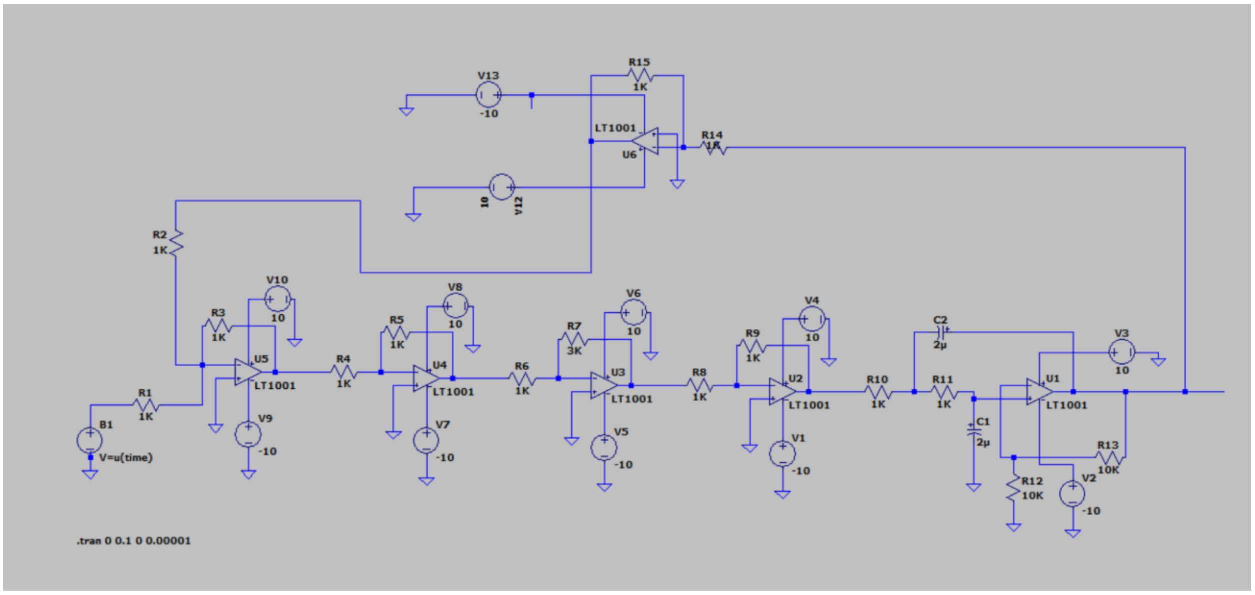
Second order system





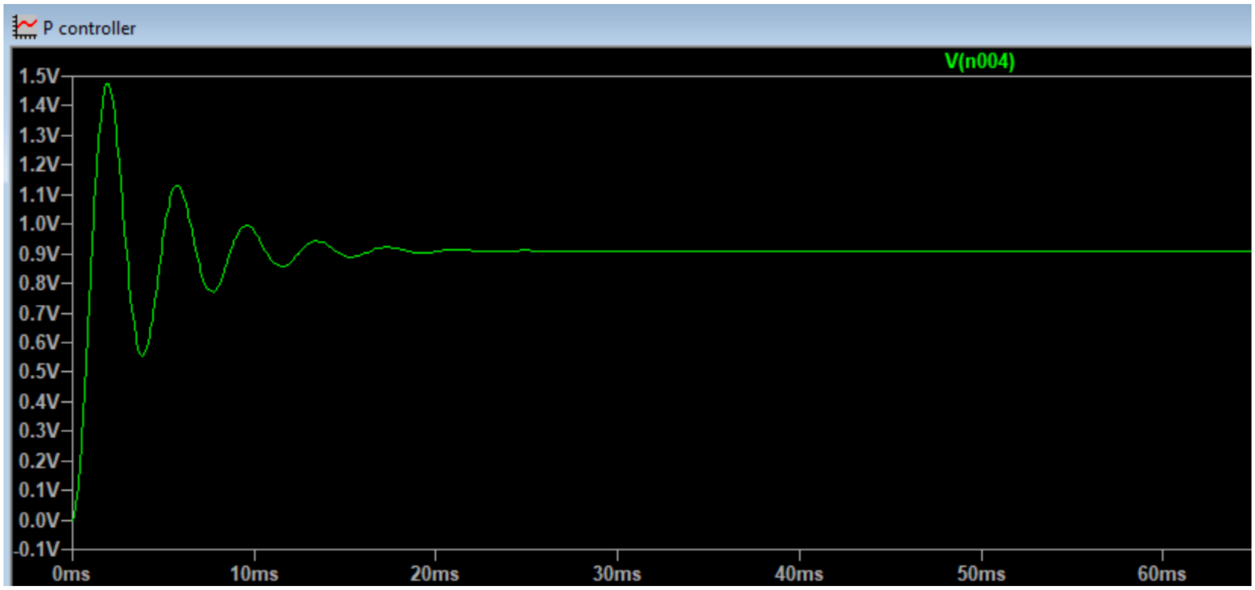
- Maximum Peak Overshoot: 0.33 V
- Rise time: 3.14ms
- Settling time: 15.88ms

Task 1 – Design of a second order system with proportional controller



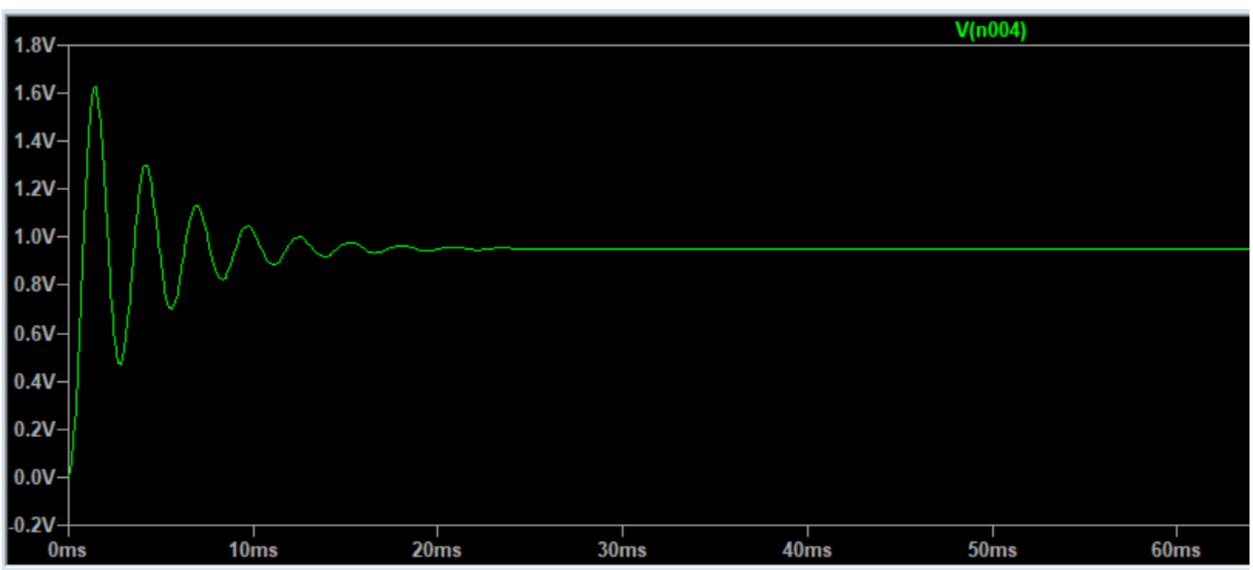
R6 (Kohm)	R7 (KOhm)	Kp	Maximum Peak Overshoot (V)	Rise time (ms)	Settling time (ms)
1	3	3	0.482	1.24-0.367 =0.873	12.22
1	5	5	0.56	0.77	16.24
1	10	10	0.65	0.48	16.97

Kp=5



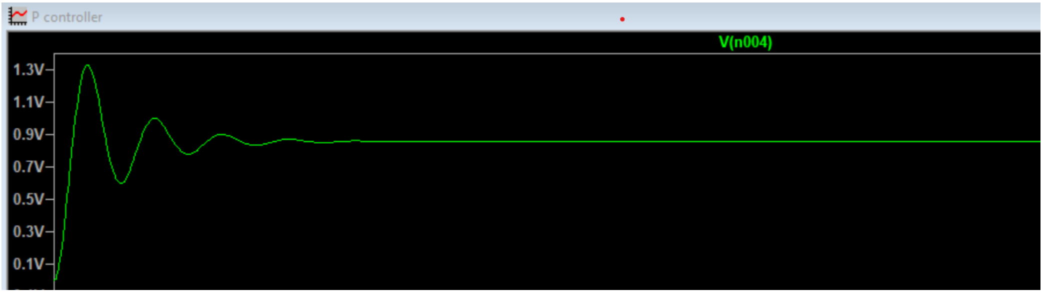
P controller
V(n004)
1.5V
1.4V
1.3V
1.2V
1.1V
1.0V
0.9V
0.8V
0.7V
0.6V
0.5V
0.4V
0.3V
0.2V
0.1V
0.0V
-0.1V
0ms
10ms
20ms
30ms
40ms
50ms
60ms

Kp=10

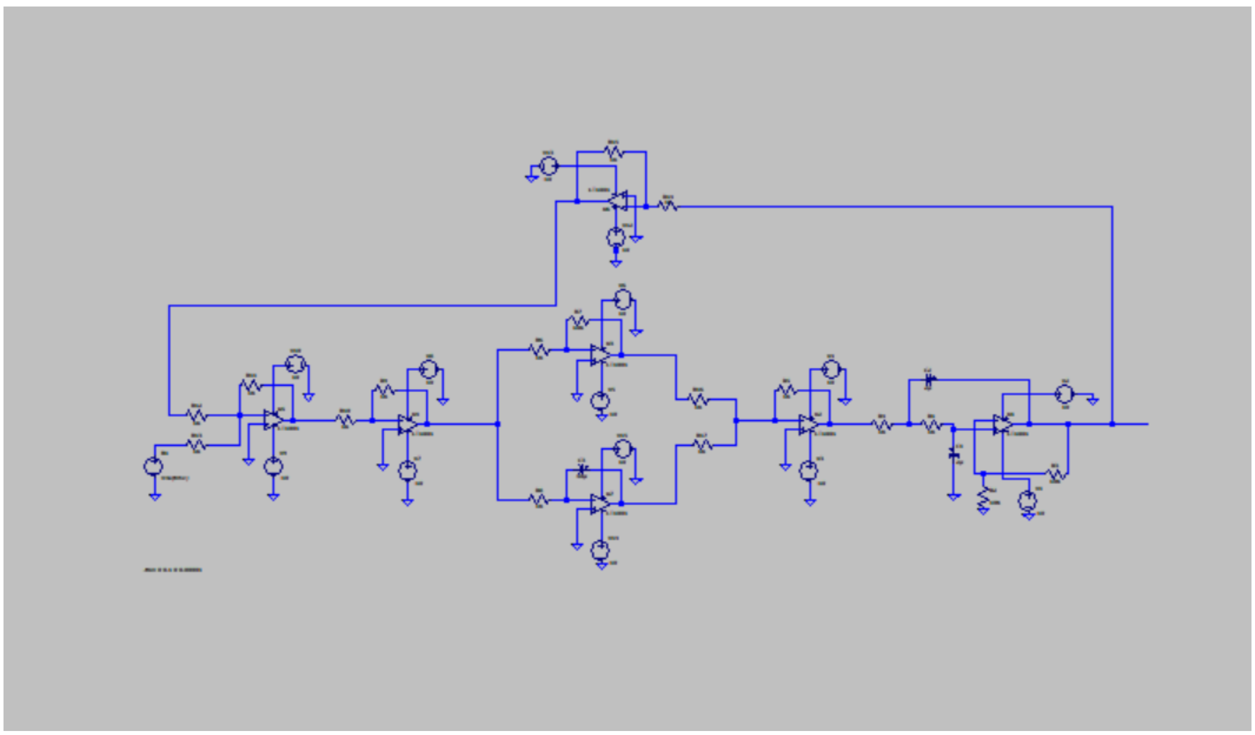


V(n004)
1.8V
1.6V
1.4V
1.2V
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
-0.2V
0ms
10ms
20ms
30ms
40ms
50ms
60ms

Kp=3

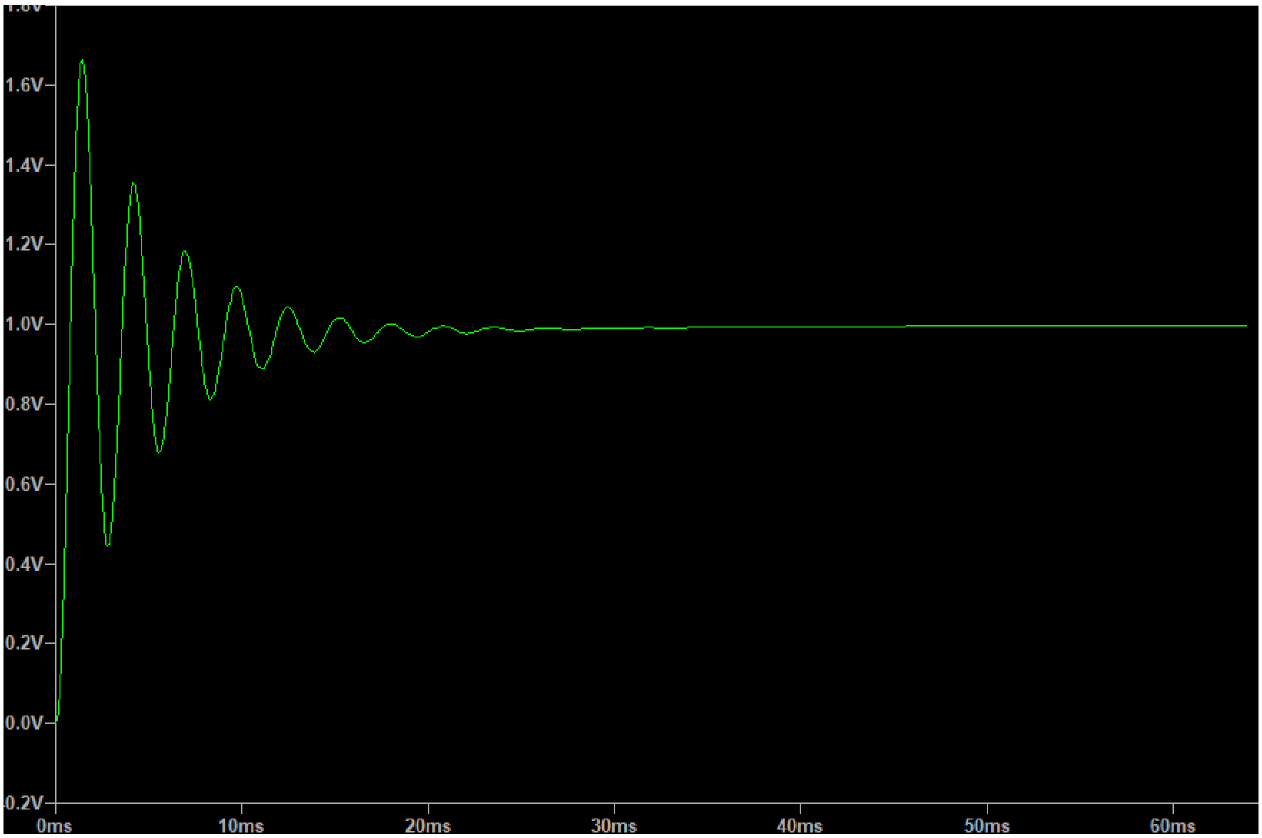


<u>Task 2 – Design of a second order system with PI controller</u>

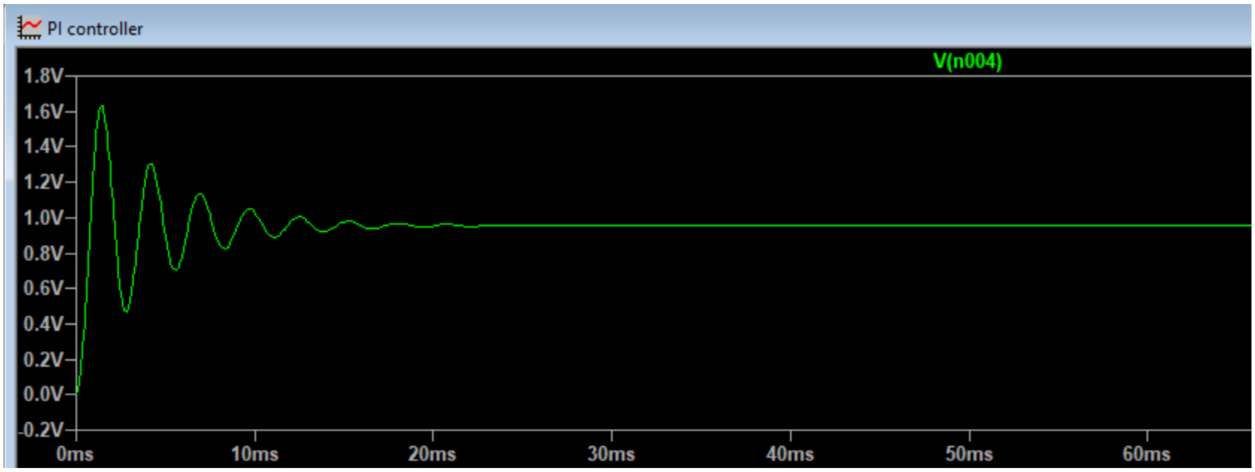


R8 (Kohm)	C3 (uF)	Ki	Maximum Peak Overshoot (V)	Rise time (ms)	Settling time (ms)
1	2	500	0.657	0.53	15.41
1	25	40	0.679	0.51	13.91
1	100	10	0.674	0.53	15.35

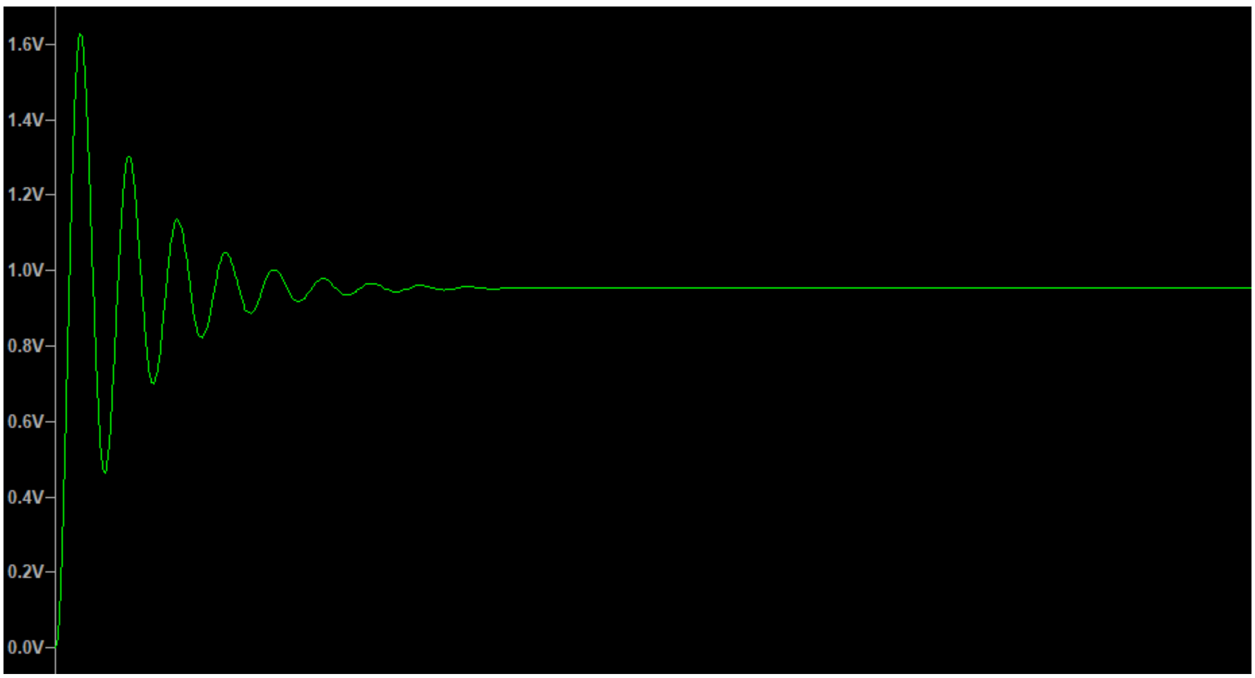
Ki=500



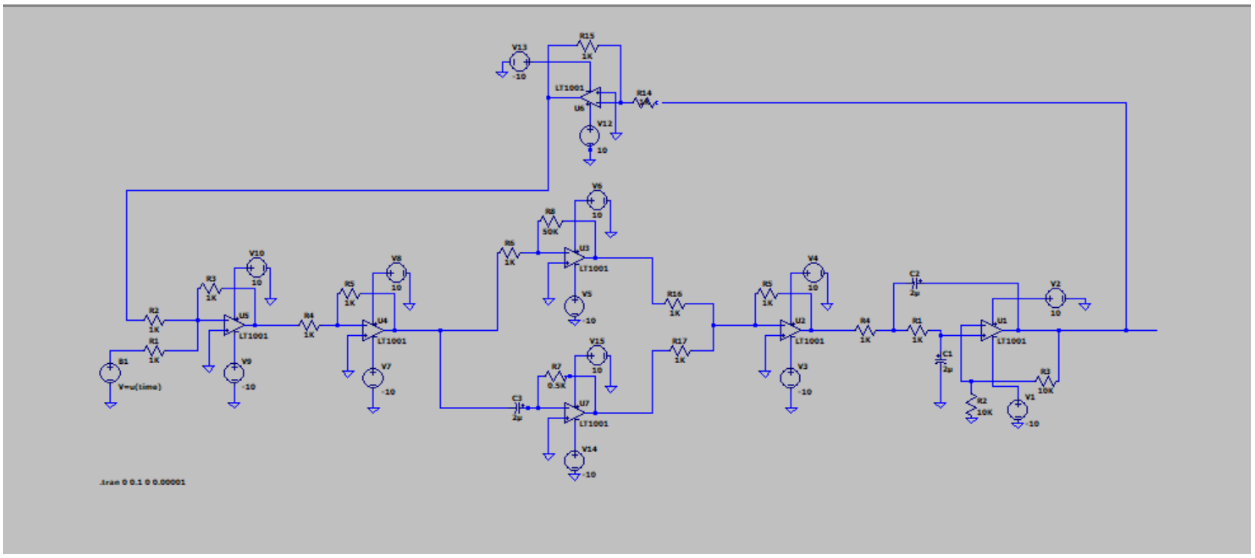
Ki=40


PI controller
V(n004)
1.8V
1.6V
1.4V
1.2V
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
-0.2V
0ms
10ms
20ms
30ms
40ms
50ms
60ms

Ki=10


1.6V
1.4V
1.2V
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V

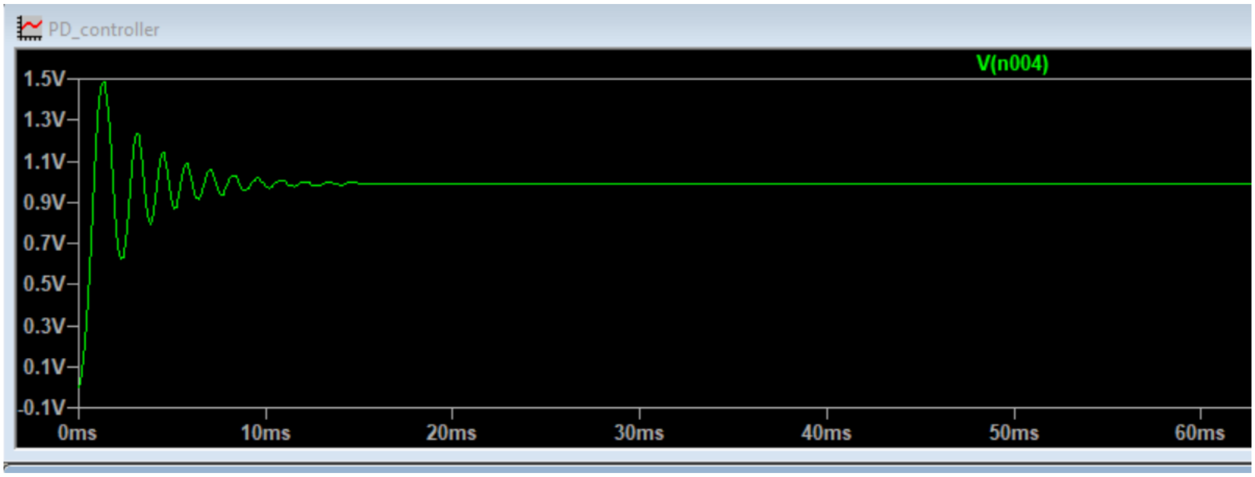
Task 3 – Design of a second order system with PD controller



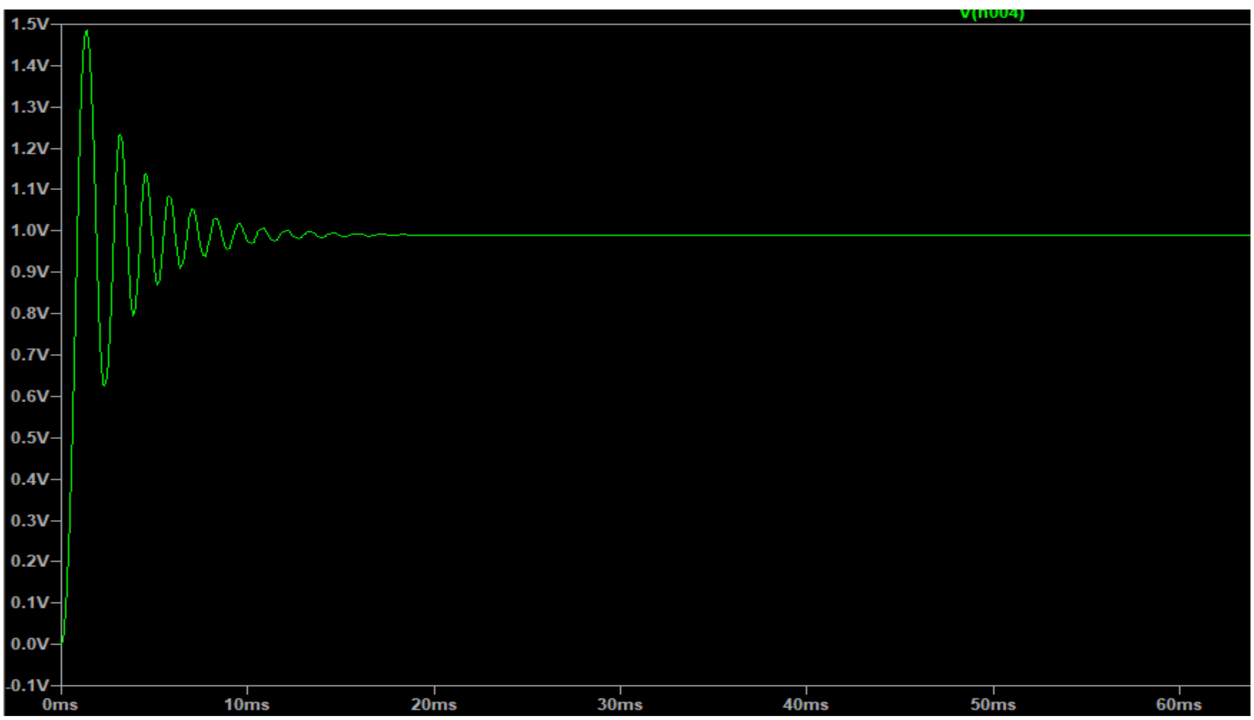
Kp=50

R18 (Kohm)	C3 (uF)	Kd	Maximum Peak Overshoot (V)	Rise time (ms)	Settling time (ms)
1	2	0.002	0.366	0.69	10.67
0.5	2	0.001	0.487	0.61	9.52
0.01	2	0.00002	0.667	0.46	30.93

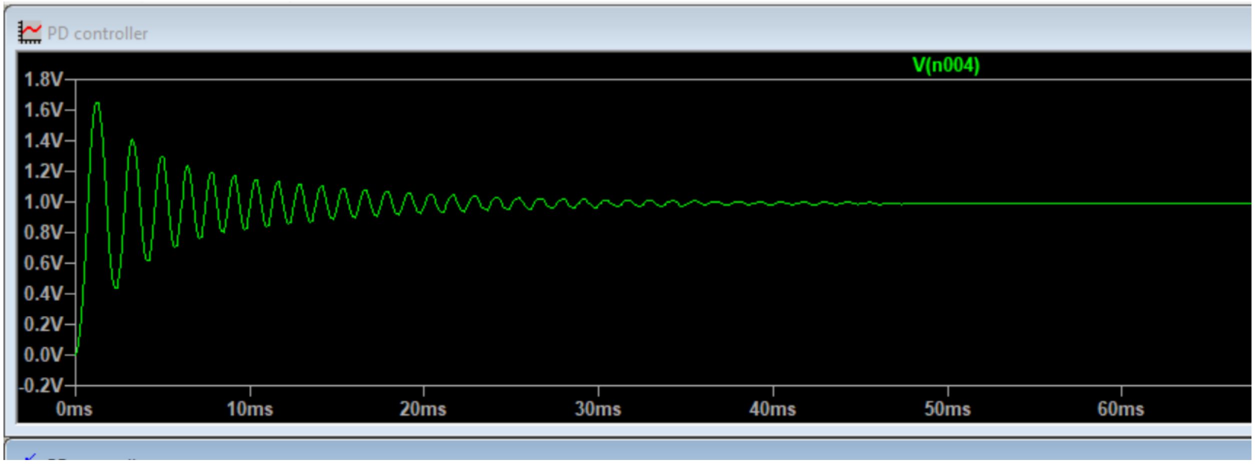
Kd=0.002, Kp=50



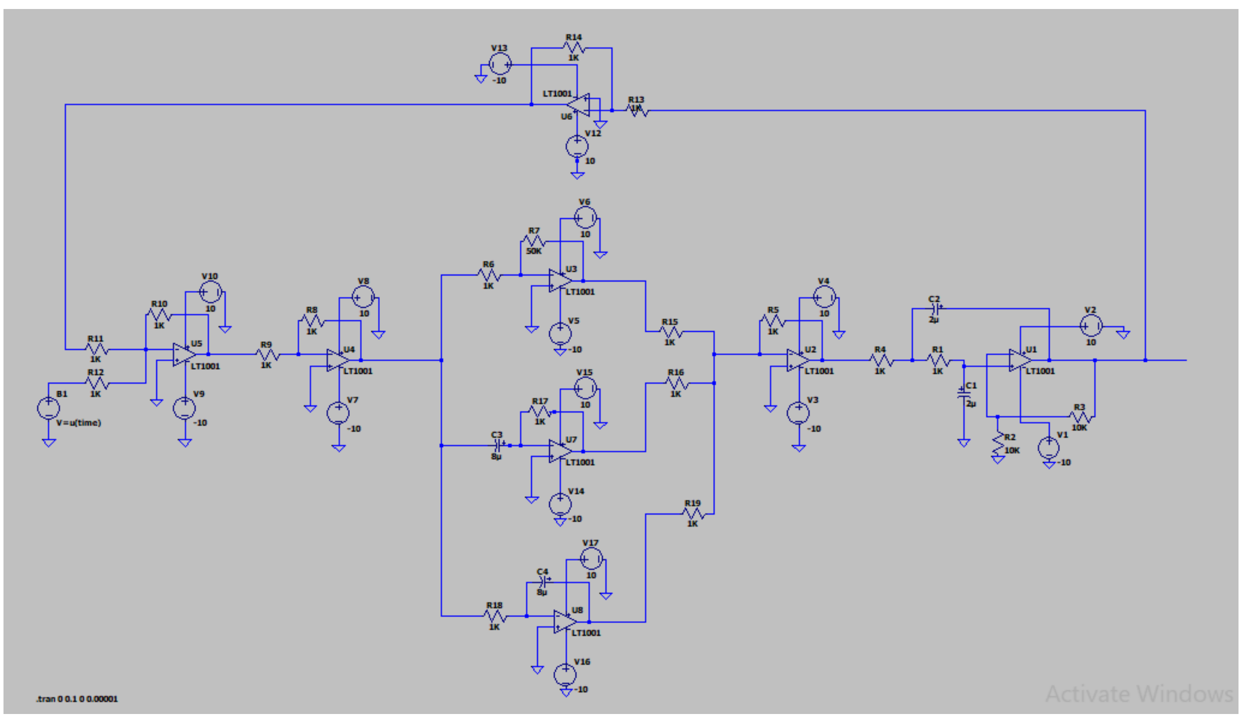
Kd=0.001, Kp=50



Kd=0.00002, Kp=50



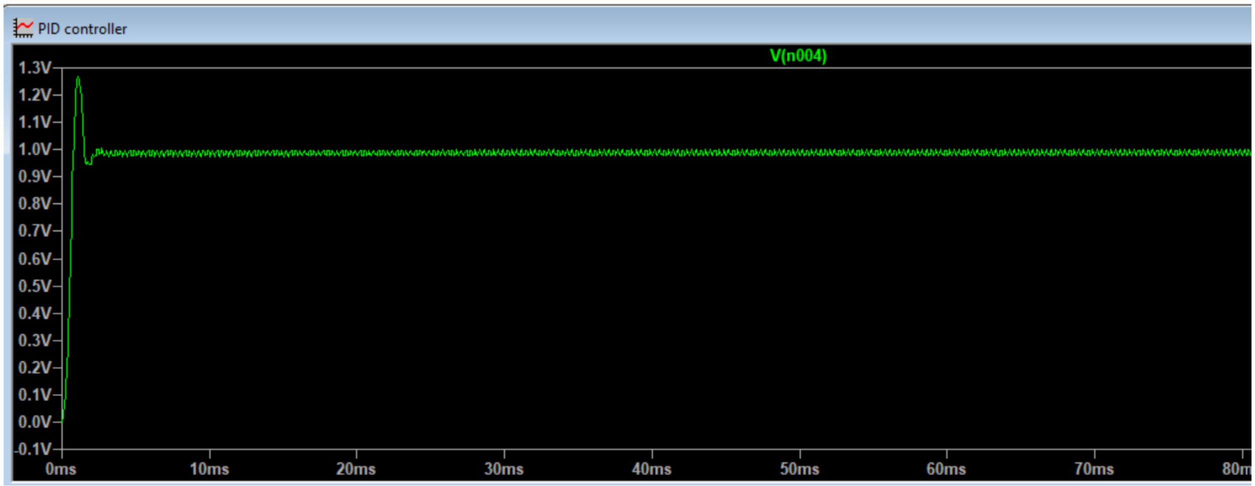
Task 4 – Design of a second order system with PID controller



Kp=50

Ki=125

Kd=0.00000008



- Maximum Peak Overshoot: 0.29 V
- Rise time: 0.51ms
- Settling time: 2.38ms

Discussion

01)

Constant Change	Maximum Peak Overshoot	Rise Time	Settling Time
Increase in Kp	Increases	Decreases	Decreases
Decrease in Kp	Decreases	Increases	Increases
Increase in Ki	Increases (If significantly increased)	Decreases	Decreases
Decrease in Kp	Decreases (If significantly Decreased)	Increases	Increases
Increase in Kd	Decreases	Decreases	Decreases
Decrease in Kp	Increases	Increases	Increases

In P controler

- Faster response
- Higher peak overshoot
- Longer settling time Increased sensitivity to noise

In PI Controler

The integral gain (Ki) in a PI controller is used to eliminate steady-state error. It does this by summing the error over time and applying a correction to the controller output. This correction is proportional to the accumulated error. Increasing the Ki value will make the controller more aggressive in eliminating steady-state error. However, it will not have a significant impact on the maximum peak overshoot, rise time, and settling time. This is because these parameters are primarily determined by the proportional gain (Kp) of the controller.

In PD controler

- Increasing the derivative gain (Kd) in a PD controller will decrease the rise time and overshoot, but it will also increase the sensitivity to noise and the risk of instability.

In PID controler

- Increasing the proportional gain (Kp) in a PID controller will decrease the rise time and steady-state error, but it will also increase the overshoot and sensitivity to noise.
- Increasing the integral gain (Ki) in a PID controller will eliminate steady-state error, but it will not have a significant impact on the rise time, overshoot, or settling time.
- Increasing the derivative gain (Kd) in a PID controller will decrease the rise time and overshoot, but it will also increase the sensitivity to noise and the risk of instability.

02)Importance of a PID controller in a control system.

A PID controller is a control loop feedback mechanism that is widely used in industrial and commercial applications to control process variables such as temperature, pressure, flow, and speed. It is a robust and simple controller that is easy to implement and tune.

PID controllers are important for the following reasons:

- They are very effective at controlling a wide variety of systems. PID controllers can be used to control systems with linear or nonlinear characteristics, and they can be used to control systems with slow or fast dynamics.
- They are very robust. PID controllers are not sensitive to small changes in the system parameters, and they can perform well even in the presence of noise and disturbances.
- They are easy to implement and tune. PID controllers are relatively simple to implement in hardware or software, and the parameters of the controller can be easily tuned to achieve the desired performance.

PID controllers applications

- Process control: PID controllers are used to control process variables such as temperature, pressure, flow, and level in a wide variety of industries, including chemical processing, food processing, and oil and gas production.
- Motion control: PID controllers are used to control the speed and position of motors and actuators in a wide variety of applications, including robotics, machine tools, and aircraft control.
- Environmental control: PID controllers are used to control temperature, humidity, and ventilation in buildings and other environmental control systems.

PID controllers are an essential part of many industrial and commercial control systems. They are robust, reliable, and easy to use, and they can be used to control a wide variety of systems.

Here are some specific examples of how PID controllers are used in the real world:

- PID controllers are used to control the temperature in your home or office.
- PID controllers are used to control the speed of the conveyor belt in a factory.
- PID controllers are used to control the flow of water in a water treatment plant.
- PID controllers are used to control the position of the robotic arm in a manufacturing plant.
- PID controllers are used to control the altitude of an airplane.

03)

Open loop transfer function

$$G(s) = \frac{Y(s)}{E(s)} = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

Characteristic equation

$$\Delta = s^2 + 2\xi\omega_n s + \omega_n^2$$

For unit step function

$$R(s) = \frac{1}{s}$$

$$= \frac{\omega_n^2}{(s^2 + 2\xi\omega_n s + \omega_n^2)s}$$

$$y(t) = 1 - \frac{e^{-\xi\omega_n t}}{\sqrt{1-\xi^2}} \sin\left(\omega_n\sqrt{1-\xi^2}t + \cos^{-1}\xi\right)$$

$$t_{max} = \frac{\pi}{\omega_n\sqrt{1-\xi^2}}$$

$$C_{max} - 1 = e^{-\pi\xi/\sqrt{1-\xi^2}}$$

Rise time $= t_r = \dfrac{1 + 1.1\xi + 1.4\xi^2}{\omega_m}$

setting time $t_s = 4/\xi\omega_n$

Second-order System	Damping Ratio (ξ)	Setting Time (T_S)
Underdamped	0<ξ<1	$T_S = \frac{4}{\zeta\omega_n}$
Undamped	ξ = 0	$T_S = \infty$
Critical damped	ξ = 1	$T_S = \frac{6}{\omega_n}$
Overdamp	ξ > 1	Depends on dominant pole

03)

<u>In a motion control system</u>

In a motion control system, the PID controller measures the current position or speed of the system and compares it to the desired position or speed. The controller then calculates an error signal, which is the difference between the current position or speed and the desired position or speed. The controller then outputs a control signal that is proportional to the error signal. The control signal is used to adjust the torque or force of the system to reduce the error.

For example, a PID controller can be used to control the speed of a robotic arm. The controller would measure the current speed of the arm and compare it to the desired speed. The controller would then calculate an error signal and output a control signal to the motor that drives the arm. The control signal would adjust the torque of the motor to increase or decrease the speed of the arm, depending on the error signal.

PID controllers can also be used to control the position of a system. For example, a PID controller can be used to control the position of a robotic arm as it picks up and places objects. The controller would measure the current position of the arm and compare it to the desired position. The controller would then calculate an error signal and output a control signal to the motor that drives the arm. The control signal would adjust the torque of the motor to move the arm to the desired position.

PID controllers are a versatile and powerful tool that can be used to improve the performance of motion control systems. They are used in a wide variety of industries, including manufacturing, robotics, and aerospace.

Here are some specific examples of how PID controllers are used in motion control applications:

- Robotic arms: PID controllers are used to control the speed and position of robotic arms in a variety of applications, such as pick-and-place operations, welding, and assembly.
- Machine tools: PID controllers are used to control the speed and position of spindles and other actuators in machine tools, such as CNC lathes and milling machines.
- Aircraft: PID controllers are used to control the altitude, airspeed, and heading of aircraft.
- Automotive: PID controllers are used to control the speed of engines, the idle speed of vehicles, and the cruise control system.

PID controllers are an essential part of many motion control systems. They allow for precise and accurate control of the speed and position of systems, which is essential for many industrial and commercial applications.

PID controllers are widely used in food processing to control a variety of process variables, such as temperature, humidity, and cooking time. This is done by continuously measuring the current value of the process variable and comparing it to the desired value. The PID controller then calculates an error signal, which is the difference between the current value and the desired value. The controller then outputs a control signal to the actuator, such as a heater, humidifier, or oven timer, to reduce the error.

PID used in food processing

PID controllers are used in food processing for a variety of reasons, including:

- Precision: PID controllers can achieve a high degree of precision in controlling process variables. This is important in food processing, where precise control of process variables is essential for ensuring product quality and safety.
- Robustness: PID controllers are robust to disturbances, such as changes in the ambient temperature or the load on the system. This is important in food processing, where the environment can be unpredictable and the load on the system can vary significantly.
- Ease of use: PID controllers are relatively easy to use and tune. This is important in food processing, where the controllers are often operated by non-technical personnel.

Here are some specific examples of how PID controllers are used in food processing:

- Temperature control: PID controllers are used to control the temperature of ovens, dryers, coolers, and other food processing equipment.
- Humidity control: PID controllers are used to control the humidity in dryers, smokehouses, and other food processing equipment.
- Cooking time control: PID controllers are used to control the cooking time of products in ovens, fryers, and other food processing equipment.
- Flow control: PID controllers are used to control the flow of liquids and gases in food processing applications, such as filling machines and mixers.
- Level control: PID controllers are used to control the level of liquids in tanks and other vessels in food processing applications.

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