Visvesvaraya National Institute of Technology (VNIT), Nagpur

Anolog Circuit Design (ECP 308)

Lab Report

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Contents

ACD mini Project: Voltage control across system using PID controller designed using OPAMP.

1.1 Title:

Voltage control across system using PID controller designed using OPAMP.

1.2 Abstract:

A PID controller is an instrument used in a wide range of applications for industrial process control such as to regulate temperature, flow, pressure, speed, and other process variables. Approximately 95% of the closed-loop operations of the industrial automation sector use PID controllers. PID stands for Proportional-Integral-Derivative. These three controllers are combined in such a way that it produces a control signal and functions based on a control loop feedback mechanism to control process variables and are the most accurate and stable controller.

PID control is a well-established way of driving a system towards a target position or level. It's practically ubiquitous as a means of controlling temperature and finds application in myriad chemical and scientific processes as well as automation. PID control uses closed-loop control feedback to keep the actual output from a process as close to the target or setpoint output as possible.

In this project, we are making optimal and effective use of analog electronic components mainly OPAMP for designing PID controller. As the name suggests, the PID controller is having three control parameters, namely, proportional, integral, and derivative-based on which it functions, we need to test each of these components separately and then integrate them. Here, we are assuming that our plant is for controlling voltage and our controller should be tunable. Therefore, implementing the components for all these three controllers is done using LM741IC OPAMP.for this purpose resistors, potentiometer, and capacitors of suitable values were chosen as shown in the circuit diagram

In many real-world scenarios, we have a voltage-sensitive system and system tuner. There it is expected that voltage across the system gets steadily tuned w.r.t our reference voltage. In such cases, the PID controller plays an important role.

Basicaly, our model takes reference voltage(that is to be set across the system) as input, computes error, and provides output to the system. Recursively, it takes feedback from the system to measure error. Note that in this project, our system is going to be **LED**. Here, we tried to design a PID Controller using OPAMP as you will see further below.

1.3 Software: Multisim.

1.4 Block diagram:

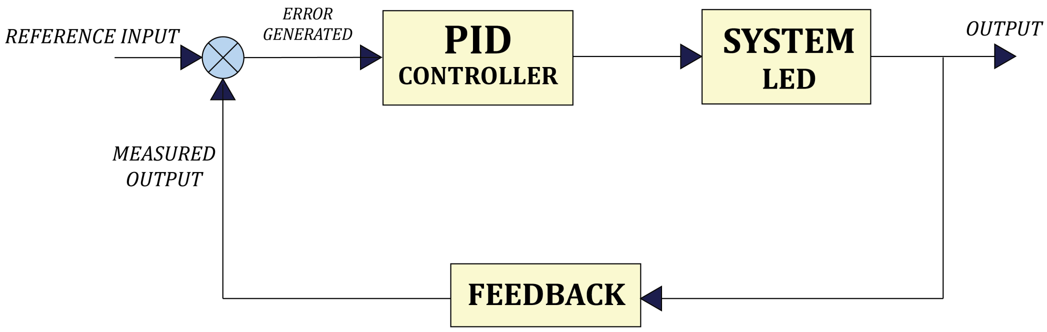

Figure 1: block diagram of CRO.

As you can see in the block diagram, the steps of designing will be as follows.

- Error counted over measured value and reference will be given as input to PID controller.
- PID controller outputs a voltage value that will be one step closer to attain reference voltage.
- Our system, in this case, is LED. Voltmeter acts as a reading component that sends feedback through Buffer back to the PID controller.

1.5 Circuit diagram:

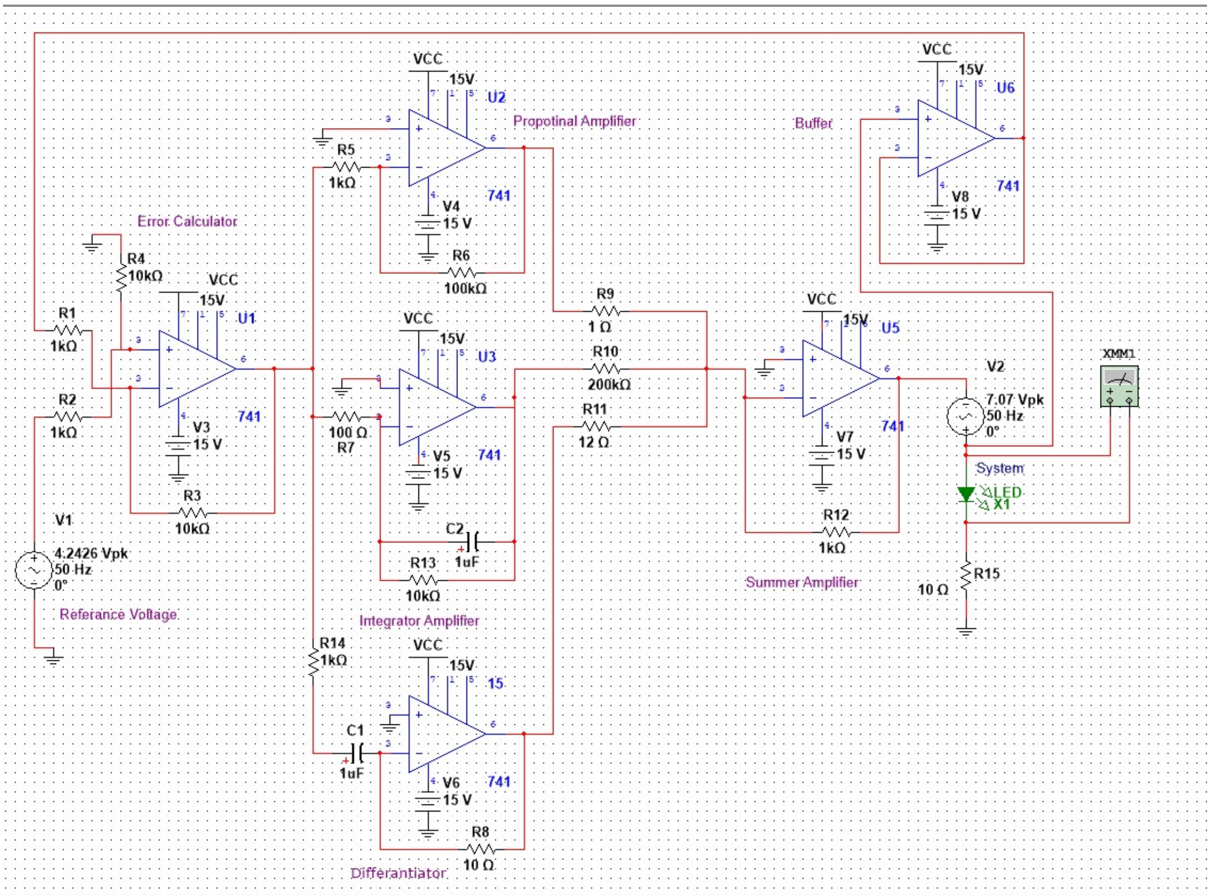

Figure 2: Circuit diagram of PID controller.

Figure 2 shows the circuit that was made in simulation software Simulink. Along with every component's name. The entire circuit was built with opamp only. Opamp with different configuration performs different function. All together in ckt, they construct PID controller.

Refer 3 With the help of this diagram let us look at each and every component of this circuit...

- Error calculation
  1. RED : Error calculation : OPAMP as difference amplifier.

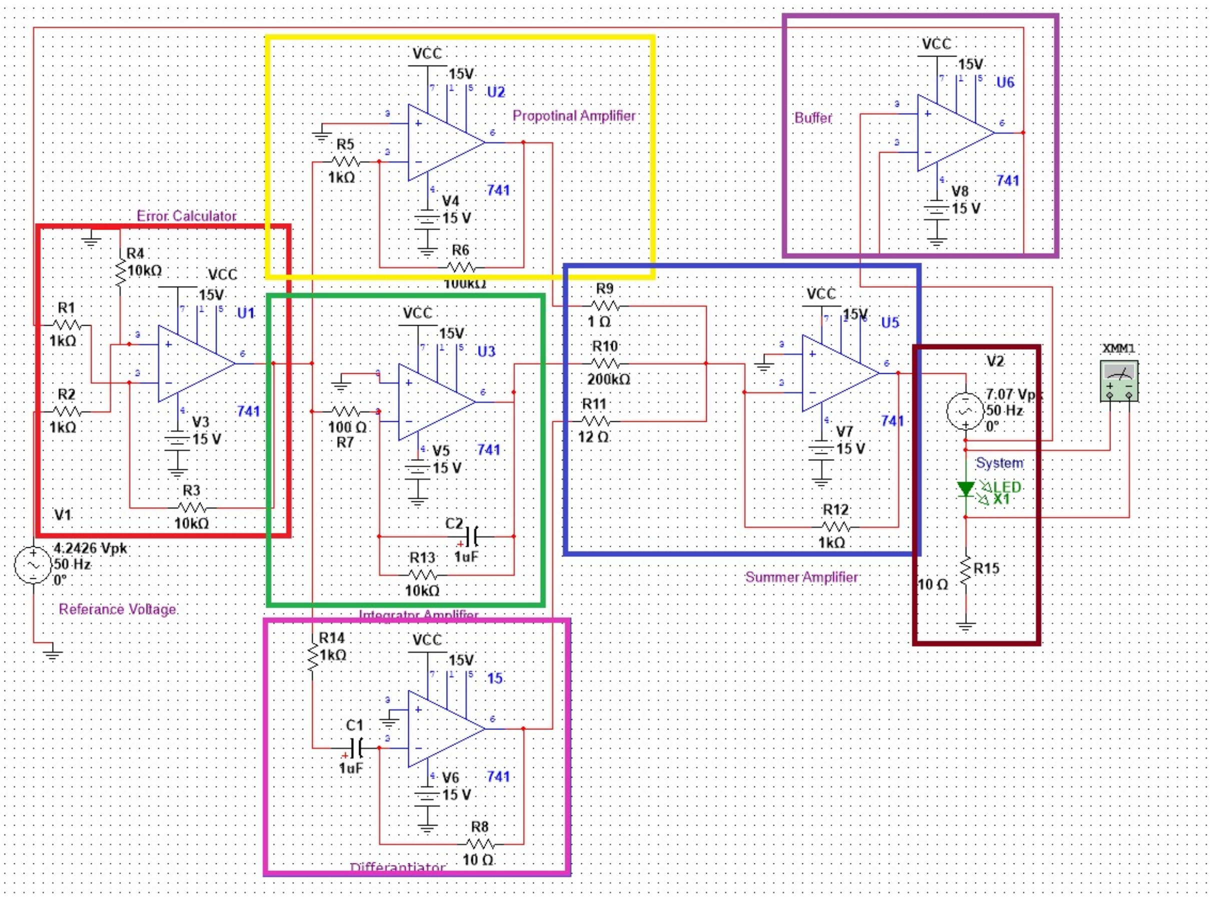

Figure 3: block diagram of CRO.

- PID
  1. YELLOW : Proportional : OPAMP as inverting amplifier
  2. PINK : Differentiator : OPAMP as differentiator.
  3. GREEN : Integrator : OPAMP as integrator.
- Feedback
  1. PURPLE : Buffer : OPAMP as a voltage follower.

Now let's have look at each and individual component in detail. Lets look at their working.

1.6 Traverse through circuit:

Op-amp- operational amplifier is the basic amplifier, which can be used by adding few components to perform various mathematical operations.

1) Inverting Op-Amp

- The following figure is of inverting Op-Amp. It is called inverting amplifier because it inverts the polarity of the voltage applied at the input.
- Here, Vo i.e., is output voltage which is fed back to inverting input terminal through Rf where it is feedback resistor.

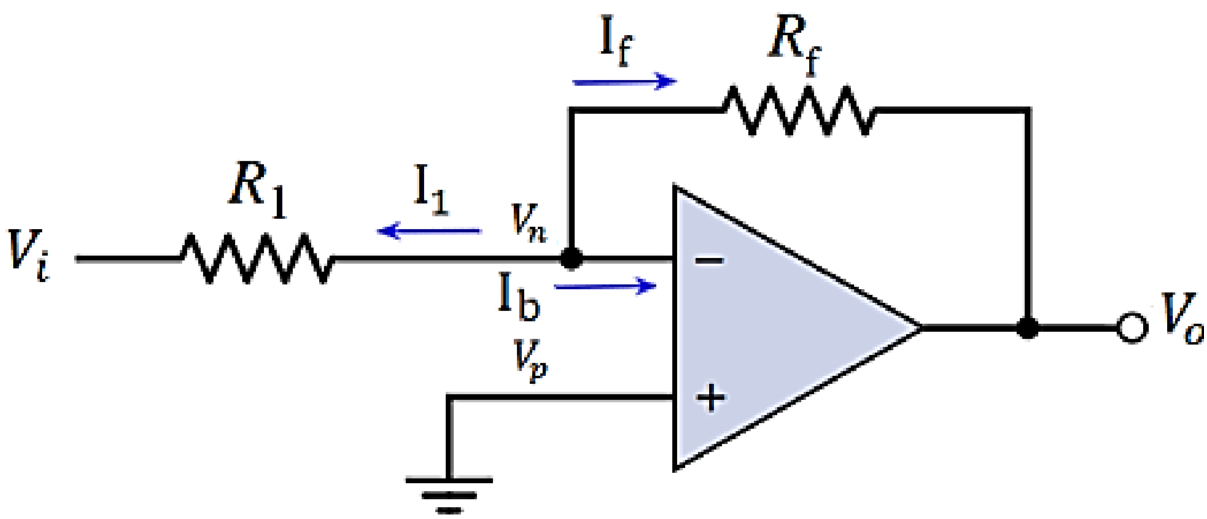

Figure 4:

2) Differentiator

- If the resistor R1 is replaced by a capacitor, an inverting Op-amp can be used as a differentiator.
- As the name suggests , circuit performs the mathematical operation of differentiation, that is output waveform is the derivative of the input waveform.
- The equation for the differentiator is as follows.

$$V_o = -RC\frac{dv_{in}}{dt}$$

- The minus sign in the formula indicates 180°phase shift in the output waveform with respect to input signal.

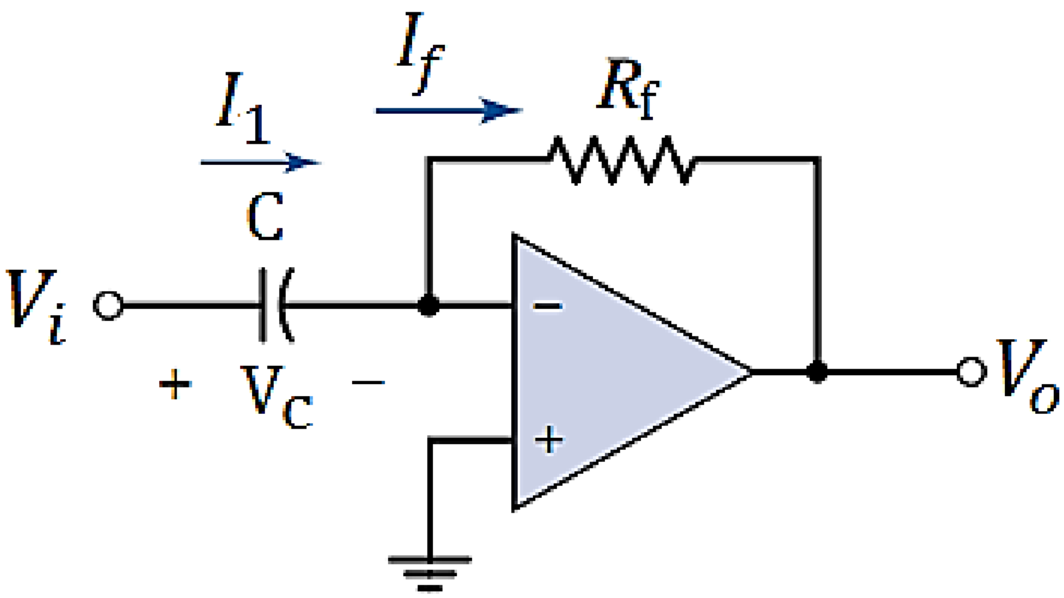

Figure 5:

3) Integrator

- If the resistor Rf is replaced by a capacitor, an inverting Op-amp can be used as integrator circuit.
- As the name suggests , circuit performs the mathematical operation of integration, that is output waveform is the integral of the input waveform. The

equation for the integrator is as follows.

$$V_o = -RC \int dV_{in} dt$$

- The circuit provides an output voltage which is proportional to the time integral of input and where is time constant of the integrator.

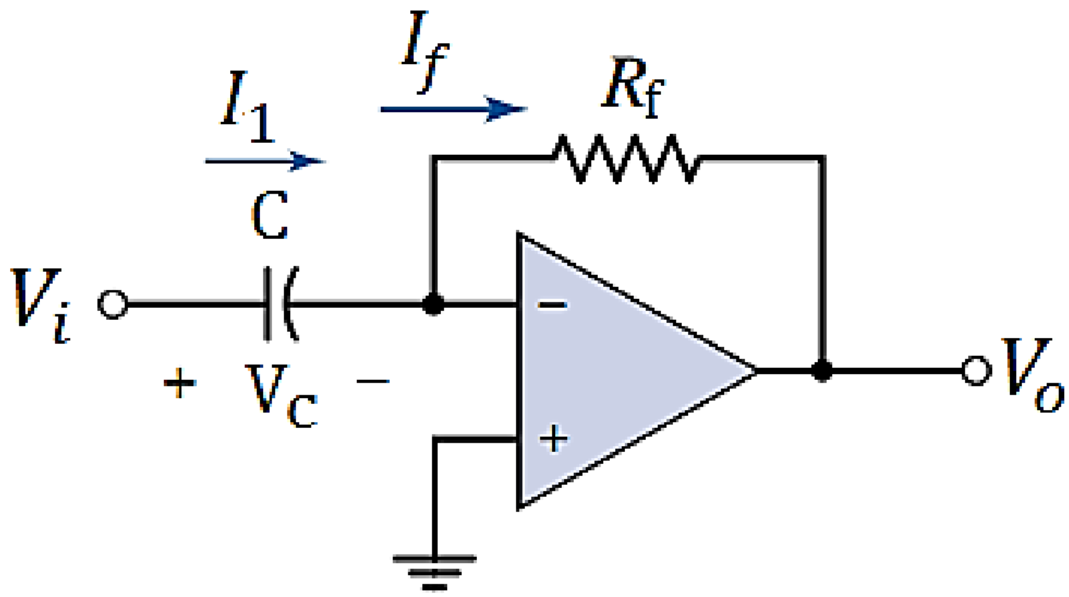

Figure 6:

4) Difference amplifier

- A differential amplifier generates an output which is difference between the outputs due to both the inputs.
- The above difference amplifier can be analysed using superposition principle i.e. by considering only 1 source in the circuit at a time.

5) Buffer or Voltage follower

- Voltage buffer which is also known as the voltage follower or unity gain amplifier, is an amplifier with its gain unity i.e., 1.

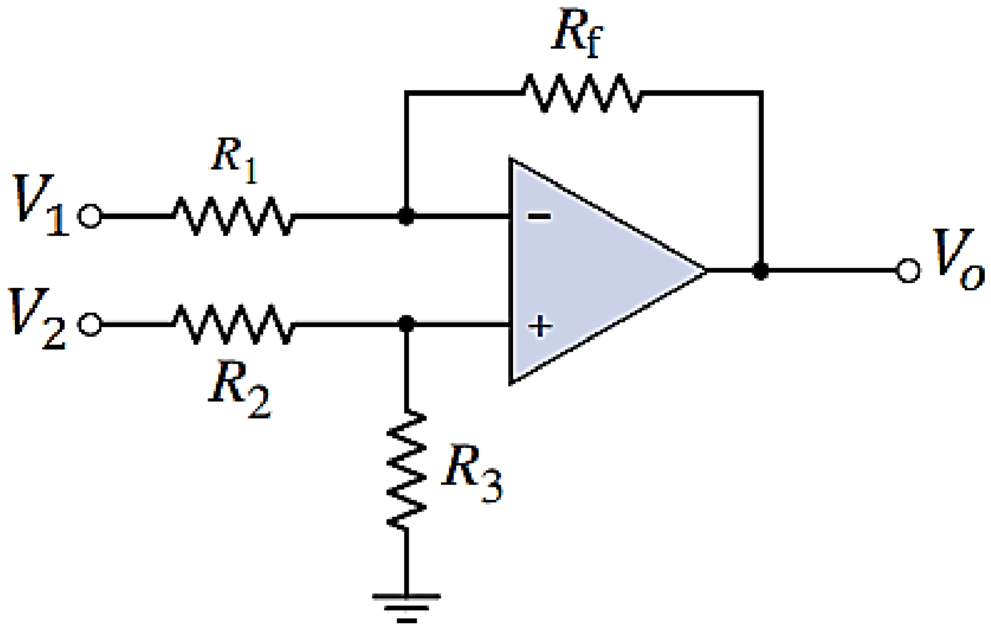

Figure 7:

- It is a special case of non-inverting amplifier having maximum negative feedback. So, voltage is also minimum.
- Even though the gain of 1 doesn't give us any voltage amplification, voltage buffer is very useful because it prevents one stage's input impedance from loading prior stage's output impedance, which causes the signal losses.

So, we saw in brief how opamp can be used in different configurations and how do they function. Now using this idea, we will look at the circuit made previously to execute the PID controller....

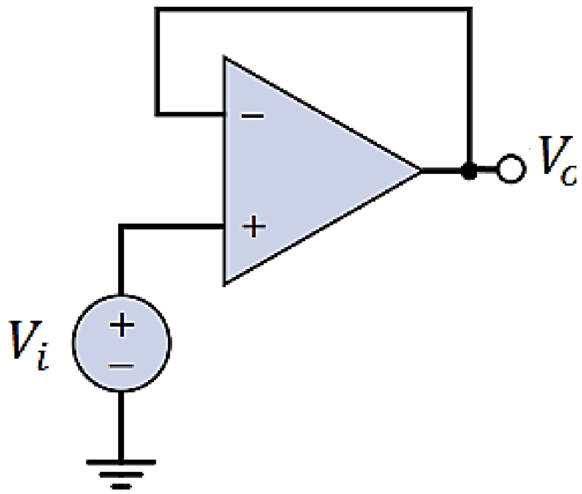

Figure 8:

1.7 Working:

- **Error Calculation**
  First of all we calculate the error using the Differential amplifier, we apply the reference voltage to the Non-inverting terminal of the op-amp and the sensor reading to the inverting terminal, so we get

$$Error = Gain * (Reference - SensorReading) \tag{1}$$

  For the accuracy purpose, we are using the gain of 10 in the difference amplifier. hence we get the required error as the input to the PID controller

- **Proportional Controller**
  Now , we have the error. for this part we are using the inverting op amp. which take the error and amplify it according to our need .

$$ProportionalGain = \frac{Rf}{R1} Error \tag{2}$$

  In this way, we get the Proportional gain using the inverting op-amp, but it should be noticed that it is inverted.

- **Integral Controller**
  we have the error from the difference amplifier , by using the op amp as a integrator with the input as Error, we get the integration of the error with respect to the time.

$$IntegralGain = RC \int Error * dt \tag{3}$$

In this way, we get the Integral gain using the inverting op-amp, but it should be noticed that it is inverted.

- **Derivative Controller**
  we have the error from the difference amplifier, by using the op-amp as a differentiator with the input as Error, we get the differentiation of the error concerning the time.

$$DifferentialGain = \frac{1}{RC}\frac{dError}{dt} \tag{4}$$

  In this way we get the Differential gain using the inverting op amp , but it should be notice that it is inverted.

- **Adding all Gains**
  we have calculated all gains now we going to add all the gains by using an op-amp as the inverting summing amplifier, we are using the inverting because ore gains are inverted in the last stage.

$$OverallGain = -Rf(\frac{P.G}{R1} + \frac{I.G}{R2} + \frac{D.G}{R3}) \tag{5}$$

- **Inputs to the System**
  After getting the overall gain we add it to the input of the system so that output changes according to our requirements. In our case, we are applying it to the -ve terminal of the dc source so that potential at the +ve terminal may decrease or increase

- **Taking Sensor Reading**
  For this we are using an op-amp as buffer cause buffer has high input impedance so no current will flow through it, this will not produce any side effects on the system. In this way, we are taking the sensor reading using buffer

- **System**
  For the simulation purpose only we are using LED as the system, we can replace our system with the other device which required voltage regulation

- In this way the Circuits works and gives the required voltage across the system

1.8 Tuning parameters:

Trial and error PID tuning method

The trial-and-error method is relatively easy, once you get a clear understanding of PID parameters. It steps through the parameters from proportional to integral to derivative. Usually, you start from an existing set of parameters from which you perform small tweaks to improve the response. For new PID loops, you start with a rough and safe initial guess.

One considers:

- The P-action is introduced to increase the speed of the response. Exaggerated P-action results in oscillation. It refers to parameter K_p.
- The I-action is introduced to obtain a desired steady-state response. The disadvantage is a higher oscillating response over a longer period. It refers to parameter K_i.
- The D-action is introduced for damping purposes. The disadvantage is the fact that oscillation on a high frequency is more probable, plus the sensitivity to the noise. It refers to parameter K_d.

Trial and error method is easy way to obtain a reasonable result. But It's time-consuming. It takes a long time to achieve good performance.

How do we tune these parameters??
Answer: Inverting Summer amplifier

Summer amplifier is another application of OPAMP. It is used to get the weighted average of inputs.

$$V_o = -R_f(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3})$$

Where V1, V2, V3 will be outputs through P, I, D components. So, we can say,
$K_p = \frac{-R_f}{R_1}$
$K_i = \frac{-R_f}{R_2}$
$K_d = \frac{-R_f}{R_3}$

Hence by setting Resistance values, we are setting parameters. In this way we can tune parameters.

The circuit is built. Now let's try to simulate it and try to achieve the goal...

1.9 Transient analysis:

Here we could paste analysed images only but, **A detailed video of this testing is recording and loaded over This Link.**

1. Refer 9 Here you can observe that initially, the voltage across LED was 0. This resulted in +ve Error to PID controller and a signal was provided that made to increase the output voltage. It slowly starts increasing and crosses a reference

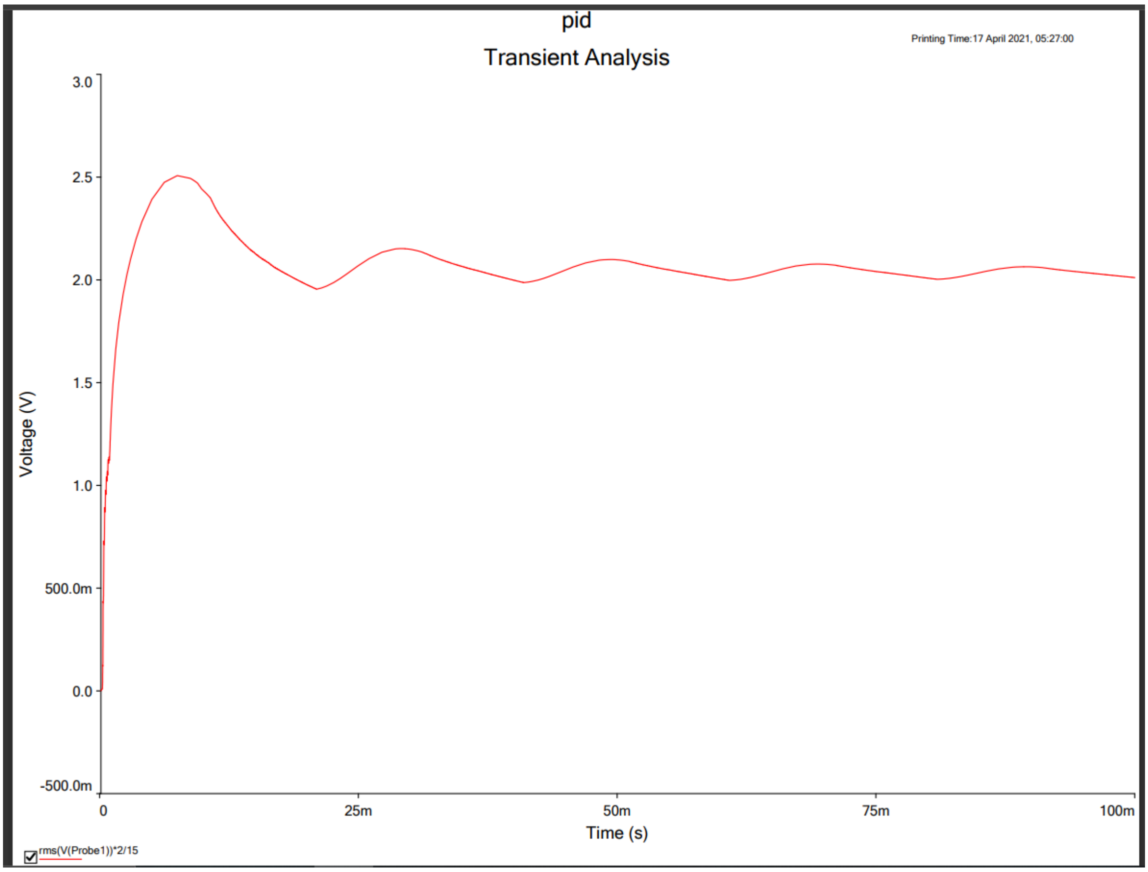

Figure 9: variation in Voltage across system with time. Reference voltage set here was 2V. It can be observed that voltage stablizes succesfully

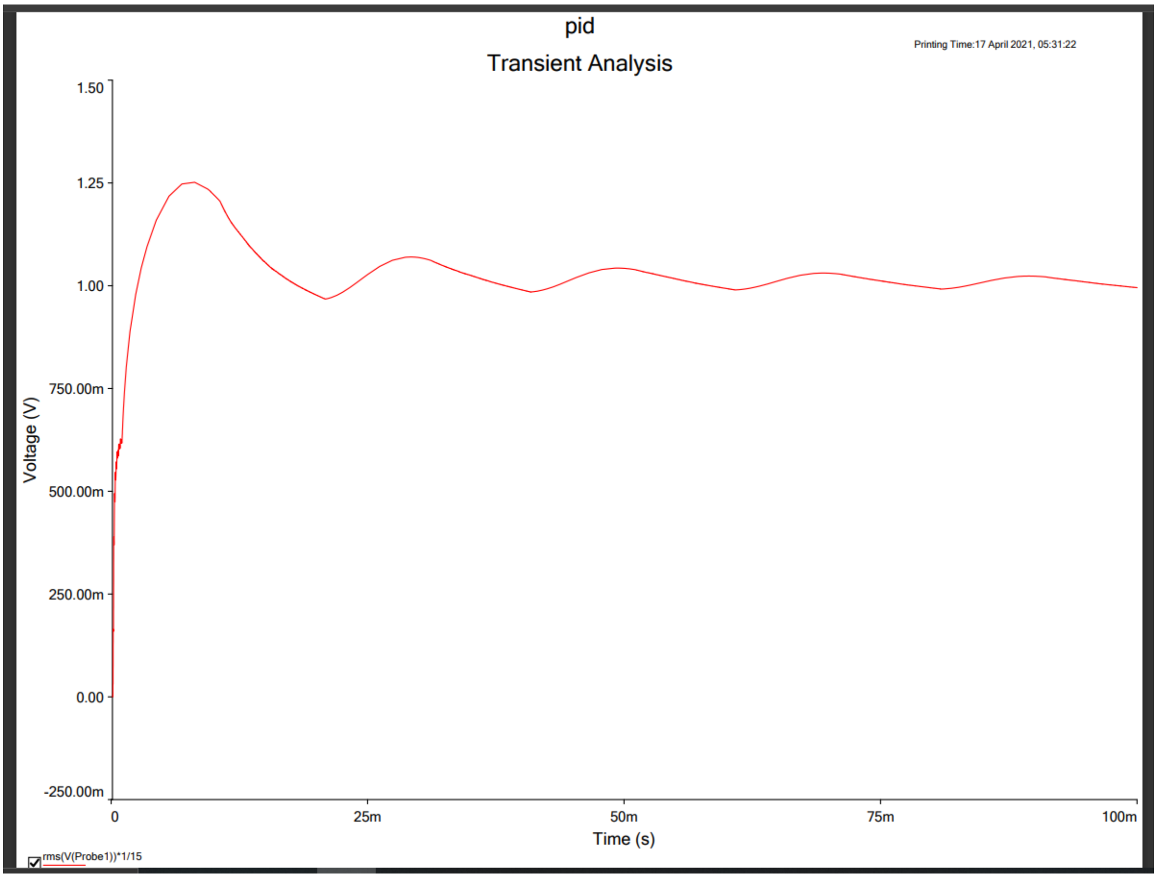

Figure 10: variation in Voltage across system with time. Reference voltage set here was 1V. It can be observed that voltage stablizes succesfully

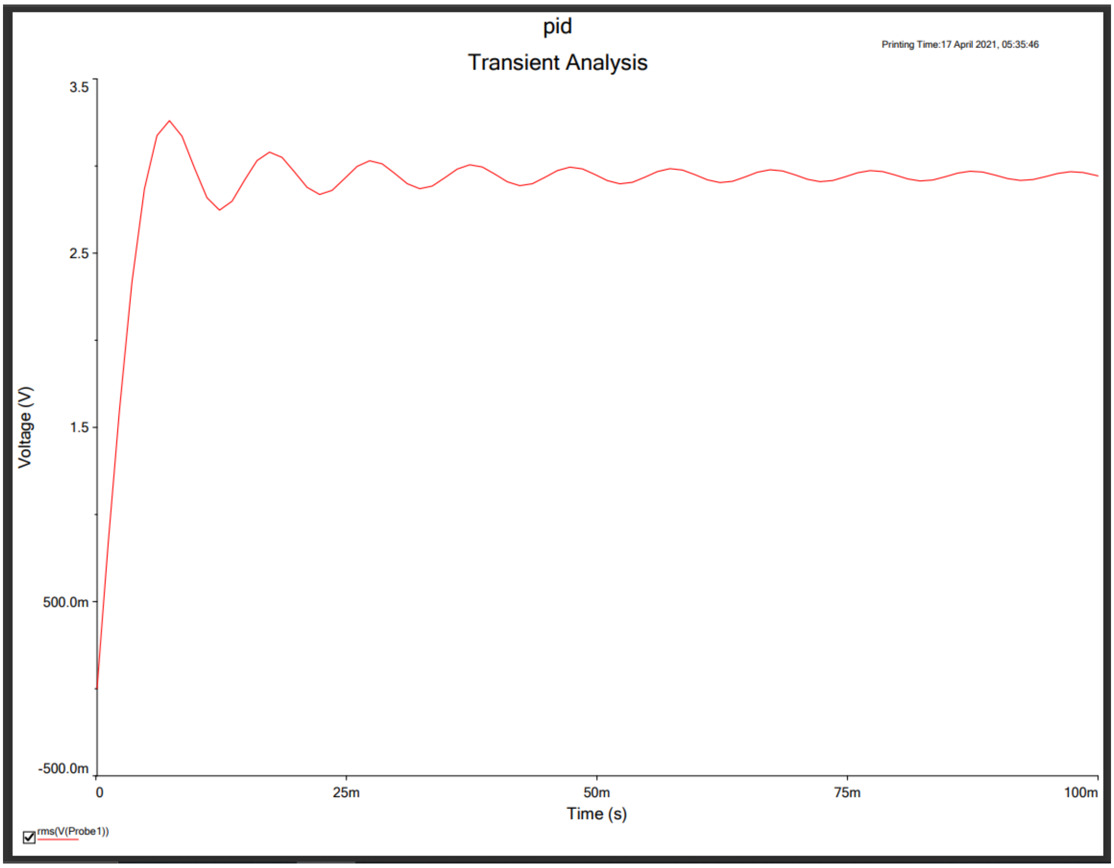

Figure 11: variation in Voltage across system with time. Reference voltage set here was 3V. It can be observed that voltage stablizes succesfully

voltage of 2V. Now due to -ve error, voltage drops down. This process goes on and oscillates till output voltage reaches the reference voltage of 2V.

Kp:Ki:Kd = 10:1:10 . Its effect can be observed in the transient analysis.

- Due to moderate Kp, the voltage reaches to reference voltage fast.
- Due to Low but moderate Ki, with PID, pushes the graph to reference voltage but with some oscillations.
- Due to moderate Kd, PID removers extra oscillations and cases faster damping that results in achieving reference voltage just in 100 ms !!!

2. Refer 10 Here you can observe that initially, the voltage across LED was 0. This resulted in +ve Error to PID controller and a signal was provided that made to increase the output voltage. It slowly starts increasing and crosses a reference voltage of 1V. Now due to -ve error, voltage drops down. This process goes on and oscillates till output voltage reaches the reference voltage of 2V.

   Kp:Ki:Kd = 100:1:8.3 . Its effect can be observed in the transient analysis.

   - Due to moderate Kp, the voltage reaches to reference voltage fast.
   - Due to Low but Ki, with PID, pushes the graph to reference voltage but with lesser oscillations.
   - Due to moderate Kd, PID removers extra oscillations and cases faster damping that results in achieving reference voltage just in 100 ms !!!

3. Refer 11 Here you can observe that initially, the voltage across LED was 0. This resulted in +ve Error to PID controller and a signal was provided that made to increase the output voltage. It slowly starts increasing and crosses a reference voltage of 3V. Now due to -ve error, voltage drops down. This process goes on and oscillates till output voltage reaches the reference voltage of 2V.

   Kp:Ki:Kd = 200:1:16.6 . Its effect can be observed in the transient analysis.

   - Due to moderate Kp, the voltage reaches to reference voltage fast.
   - Due to moderate Ki, with PID, pushes the graph to reference voltage but with some oscillations. Since reference voltage was high in this case (3V) we had to set Ki high which causes more oscillation.
   - Due to moderate Kd, PID removers extra oscillations and cases faster damping that results in achieving reference voltage just in 100 ms !!!. Kd

also had to be adjusted high

1.10 Further modification:

The model built in this project can further be extended to many other applications such as, **Temperature control**. Since the simulator lacks the availability of temperature sensors, and also due to time constraints, we had to restrict this project to voltage control only. But this could be one of the further modifications possible. Certain changes those are required-

1. Replacement of voltmeter with temperature sensor.
2. System could be replaced with an iron of any device whose temperature needs to be maintained,
3. Reference here too will be set some voltage value only. Cause at the end, whatever heat will be produced to raise or lower the temperature, will be due to power loss through filament only. It will be maintained with reference voltage only.
4. Reference voltage could be manipulated to find its temperature equivalent and that could be displayed over there.

The basic ckt and structure of PID controller will remain the same, i.e. integrator, differentiator, inverting amplifier using opamp. Just there will be a change in a system and other PID parameters can be tuned as per the requirements. Here is an example :

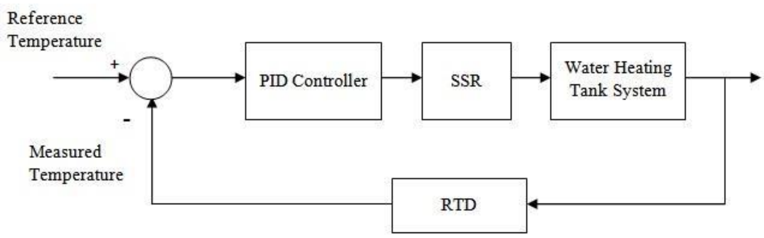

Figure 12: Temeerature control using PID controller.

1.11 Conclusion:

- PID controller was studied briefly
- OPAMP and its linear, as well as non-linear application, were studied.
- PID controller was designed using OPAMP.
- PID controller was tuned.
- A remarkable phenomenon observed is that the PID controller achieves desired output just within 100ms.
- It is shown that an Analog device such as OPAMP can be used to design a controller.
- Controller was designed and successfully implemented on Multisim software. Earlier we discovered other simulation software too and found out multisim to be most useful.
- Multisim provides a variety of features such as AC, DC analysis, transients, and real-time experience. Also, multisim processes data faster.

1.12 References:

1. https://www.omega.co.uk/prodinfo/pid-controllers.html for abstract.
2. https://www.incatools.com/pid-tuning/pid-tuning-methods/#:~:text=Trial%20and%20error%20PID%20tuning%20method&text=Usually%20you%20start%20from%20an,the%20speed%20of%20the%20response. for pid parameter tuning.
3. Book by Roy Choudhari for applications of opamp