
The Research Migration Project is an initiative of FOSSEE, IIT Bombay that promotes the use of eSim for reproducing published research circuits originally implemented using proprietary simulation tools. The objective is to migrate these validated designs to eSim to build an open source resource database.

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Title of the circuit :

Analog PID Controller for DC Motor Speed Control

Abstract :

This paper presents the design and simulation of an Analog Proportional-Integral-Derivative (PID) Controller using operational amplifiers (Op-Amps) for precise DC motor speed control. The circuit utilizes a continuous feedback loop to process the error signal through Proportional, Integral, and Derivative stages, generating a corrective control voltage that effectively minimizes steady-state error and reduces overshoot. By leveraging the characteristics of analog computing with Op-Amps, this design offers a stable and responsive solution for real-time speed regulation. This approach is particularly beneficial in robotics, industrial automation, and servo systems, where accurate speed tracking and smooth transient response are essential. The paper explores the circuit configuration, tuning parameters, and performance validation using the eSim EDA tool.

Keywords: Feedback Control Systems, PID Controller, Steady-State Error, Transient Response, Operational Amplifier.

Theory/Description :

This circuit uses operational amplifiers (Op-Amps) to build a continuous-time proportional-integral-derivative (PID) controller. The circuit comprises of three parallel signal processing stages: a Proportional amplifier (to enhance rising time), an Integrator (to minimize steady-state error), and a Differentiator (to reduce overshoot). These three signals are summed using an inverting adder to generate the control signal for the load (modelled as a DC Motor). The feedback loop creates the error signal, which the PID controller minimizes, by comparing the output speed (expressed as voltage) to a setpoint.

Reason to reproduce with eSim :

Reproducing this circuit in eSim (using the Ngspice engine) allows for the validation of control theory concepts in an open-source environment without relying on proprietary tools like MATLAB/Simulink. It demonstrates the capability of eSim to handle mixed-signal simulation and complex feedback loops. This project serves as an educational resource for students to visualize the transient response and stability of analog control systems cost-effectively.

Expected Outcome/outputs :

When simulated, the circuit is expected to show the following waveforms:

1. Transient Response: A plot of the Output Voltage (Motor Speed) rising and settling to the Setpoint Voltage with minimal overshoot and zero steady-state error.
2. Error Signal: A waveform showing the error voltage decaying to zero over time.
3. Control Signals: Individual waveforms for the P, I, and D outputs, allowing for the analysis of each component's contribution to the system stability.

Circuit Diagram :

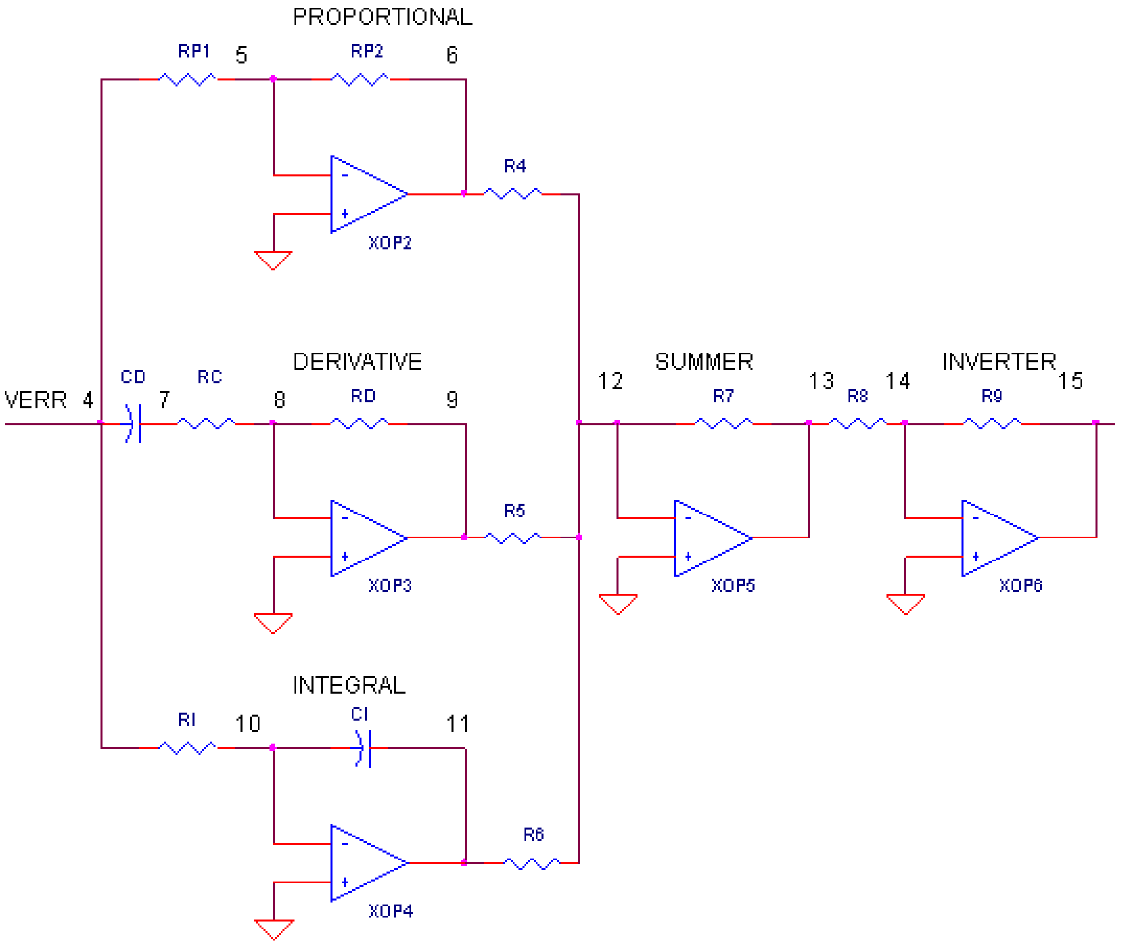

Fig 1: PID Controller

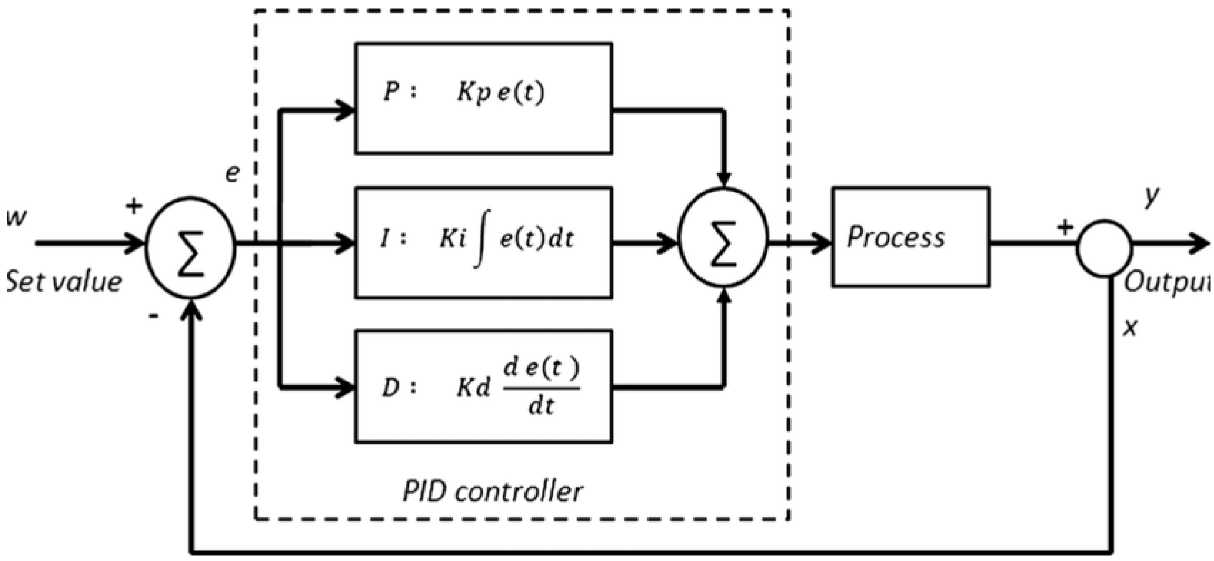

Fig 2: Block Diagram Of PID Controller

PROPOSED SYSTEM

The proposed system involves designing an analog Proportional-Integral-Derivative (PID) controller using operational amplifiers (Op-Amps) to regulate the speed of a DC motor with high precision and stability. The circuit utilizes three parallel signal processing stages—Proportional, Integral, and Derivative—to continuously calculate and correct the error between the desired setpoint and the actual motor speed. By tuning the resistor and capacitor values in each stage, the system allows for specific control over the transient response, effectively minimizing overshoot and eliminating steady-state error. This design provides a robust and efficient solution for real-time feedback control, making it suitable for industrial automation, robotics, and educational validation of control theory concepts.

ESim Circuit :

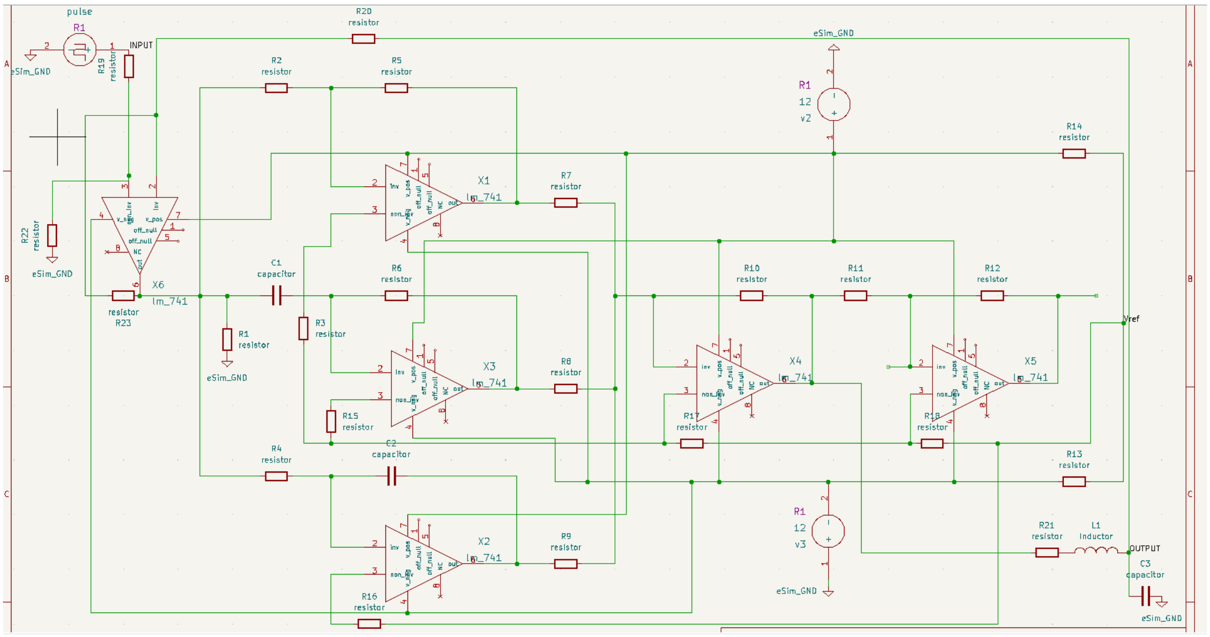

Fig3: This diagram shows the op-amp-based Analog PID Controller circuit used to regulate the speed of a DC motor. It utilizes three parallel signal processing stages to process the error signal and generate a control voltage that minimizes steady-state error and optimizes transient response.

Input Waveform :

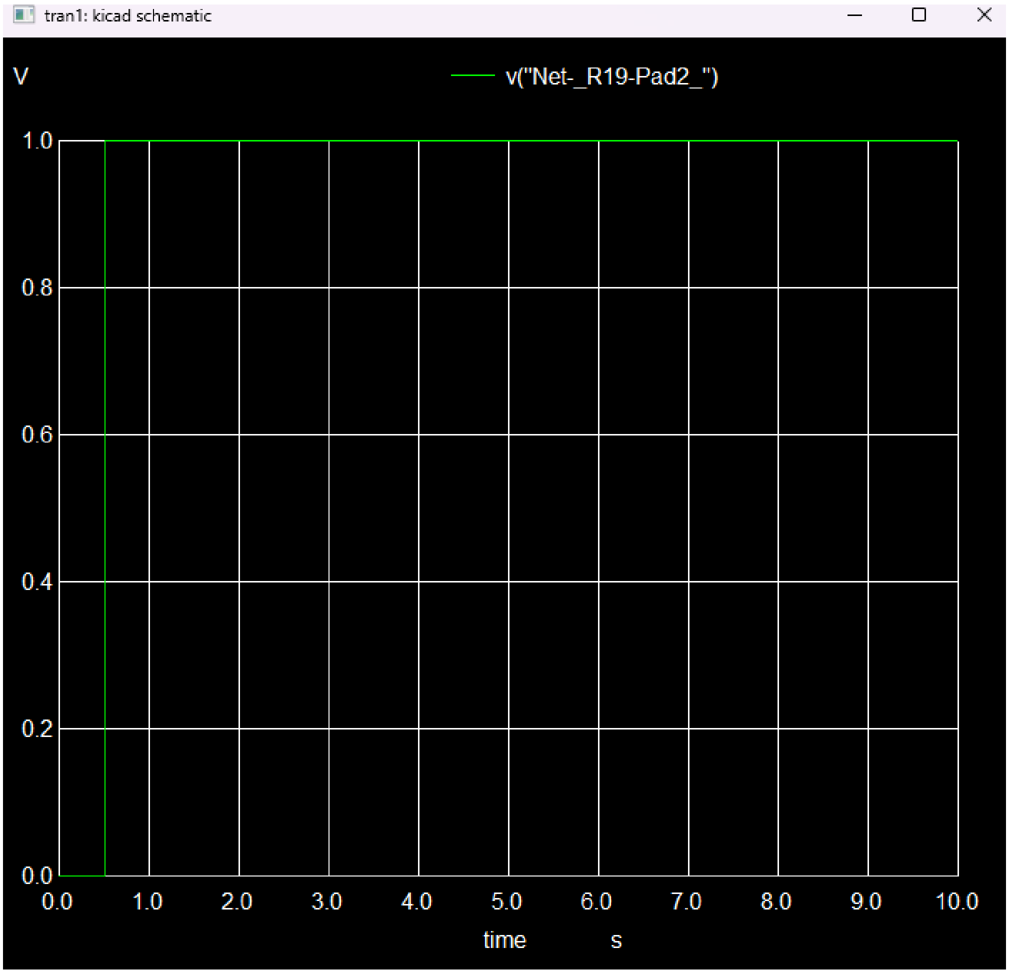

Fig 4: This figure shows the input signal provided to the PID Controller circuit, which triggers the op-amp to generate step signal.

Output Waveform :

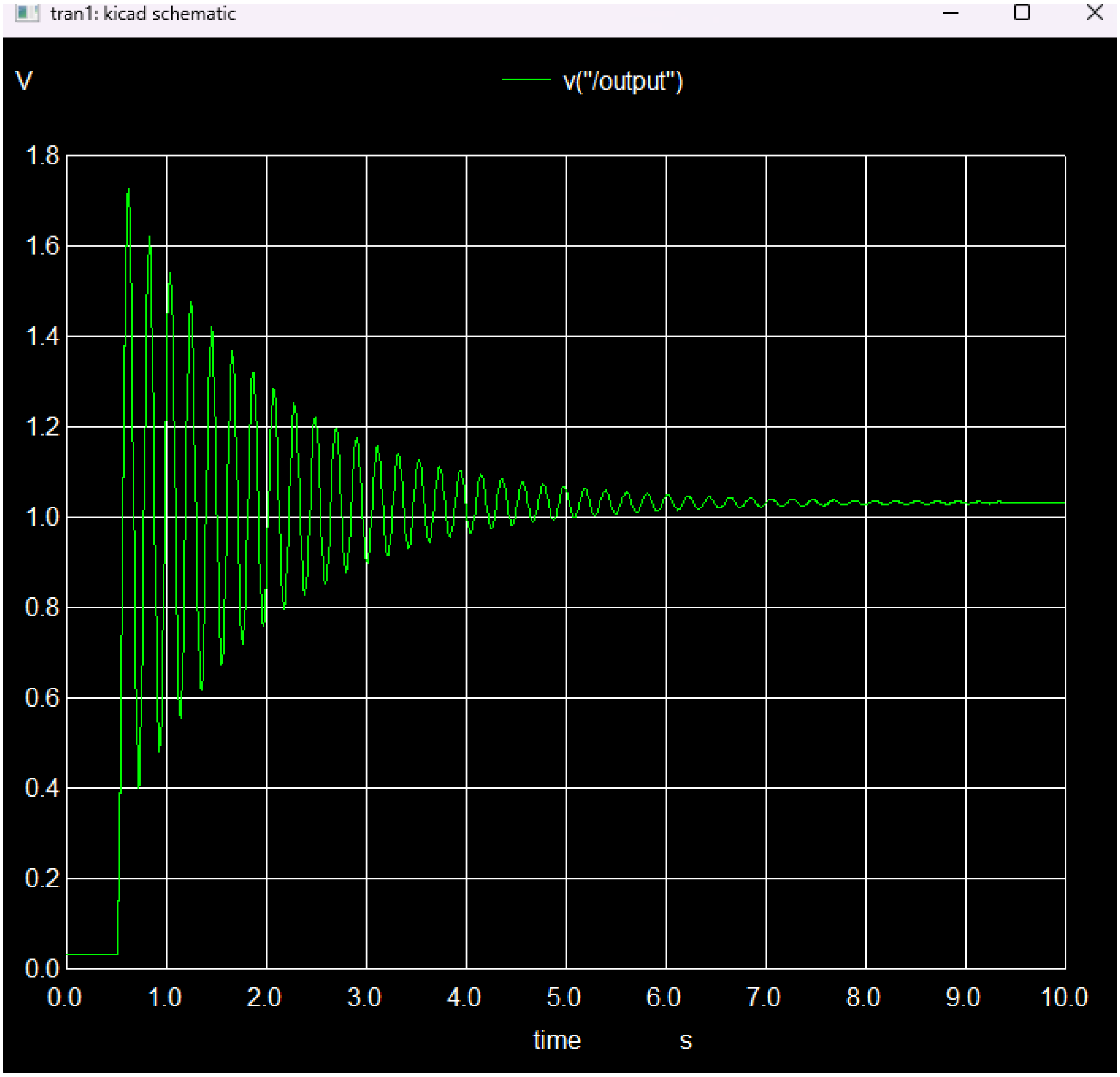

Fig 5 : This figure illustrates the output waveform generated by the PID Controller, showing a damped sinusoidal wave.

Output :

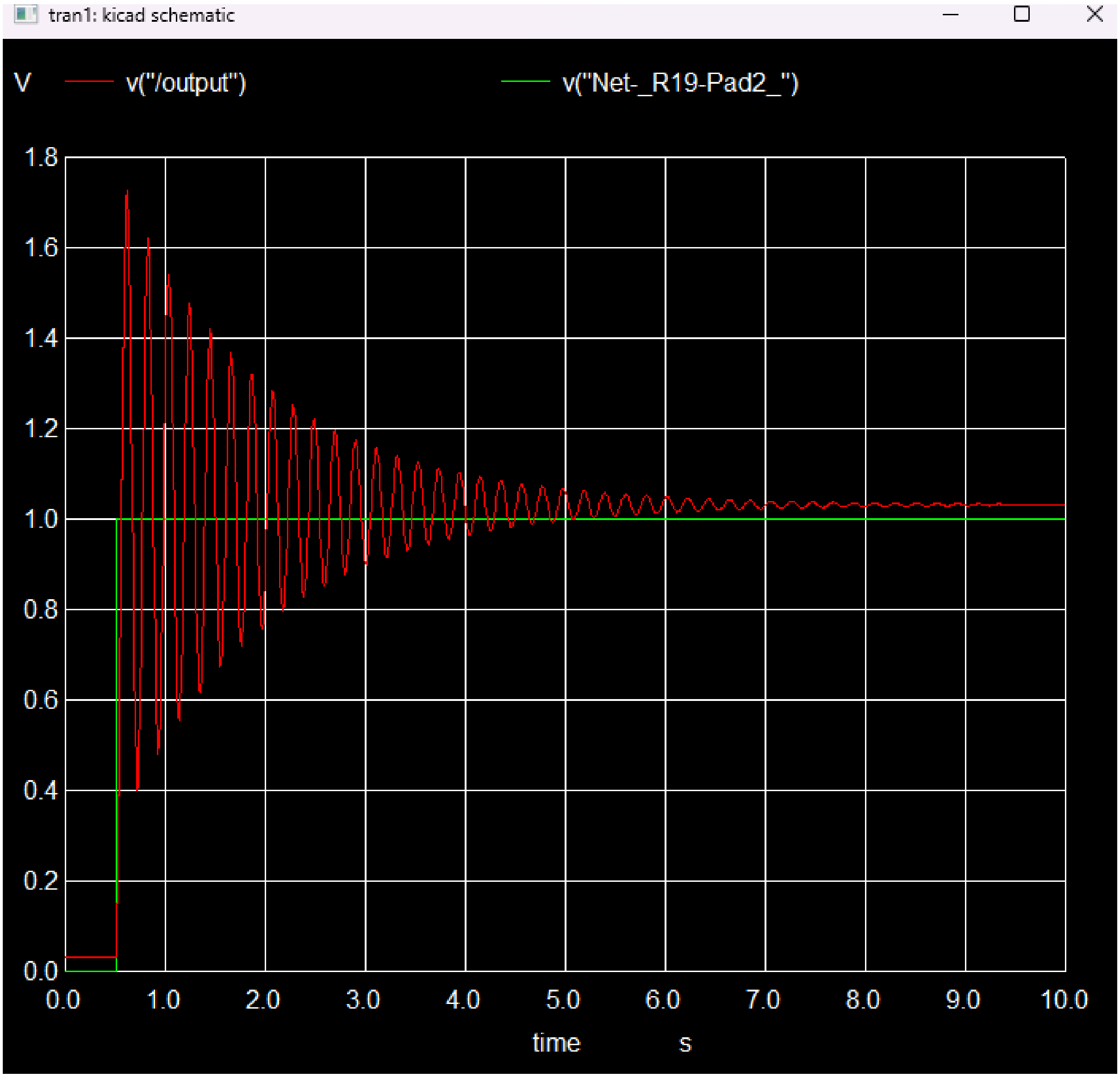

Fig 6 : Output plot

Expected Results (Input, Output waveforms and/or Multimeter readings) :

1. Input Signal (Setpoint): A step voltage signal (e.g., 0V to 1V) will be applied as the reference input. This represents the desired motor speed changing instantaneously from "Stop" to "Full Speed".

2. Output Waveform (Transient Response): The output voltage (representing actual motor speed) is expected to rise towards the setpoint value. The waveform will exhibit:

- **Rise Time: A smooth increase from 0V.**
- **Overshoot: A slight peak above 1V (depending on the Kp and Kd tuning) before correcting itself.**
- **Settling: The waveform will stabilize and flatten out exactly at the setpoint voltage (1V).**

3. Error Signal Waveform: The error voltage (measured at the output of the difference amplifier) will start at a maximum value (1V) at t=0 and exponentially decay to 0V. This validates that the Integral (I) term is correctly accumulating and eliminating steady-state error.

4. Multimeter Readings: In steady-state simulation analysis:

- **Input Node: 1.00V**
- **Output Node: 1.00V (demonstrating unity gain in closed loop)**
- **Error Node: 0.00V (demonstrating zero steady-state error)**

Advantages of Analog PID Controller:

1. **Zero Steady-State Error**
2. **Fast Transient Response**
3. **Reduced Overshoot**
4. **Flexible Tuning**
5. **Continuous Control**

Disadvantages of Analog PID Controller :

1. **Component Sensitivity**
2. **Hard to Re-tune**
3. **Noise Susceptibility**

Applications :

1. DC Motor Speed Control: Precise speed regulation in conveyor belts and robotic actuators.
2. Temperature Control: Maintaining constant temperature in industrial ovens and incubators.
3. Position Control: Servo systems for antenna positioning and CNC machines.
4. Flow Control: Regulating liquid or gas flow rates in chemical processing plants.
5. Power Electronics: Voltage regulation in power supplies and converters.

Conclusion :

In conclusion, the Analog PID Controller is a simple, effective circuit that facilitates precise speed regulation of DC motors with optimized transient response. It is widely used in applications like industrial automation, robotic actuators, and servo systems due to its ability to eliminate steady-state error and reduce overshoot, making it an essential building block in modern control system design.

Research Paper/Journal/etc. :

- Title: Op-Amps and Linear Integrated Circuits
- Author: Ramakant A. Gayakwad
- Page No.: Chapter 7 (General Linear Applications)
- Link: https://www.pearson.com/en-us/subject-catalog/p/op-amps-and-linear-integrated-circuits/P200000003206

Source/Reference(s) :

Ogata, K., "Modern Control Engineering", Pearson Education.

eCircuit Center, "Op-Amp PID Controller", Available: http://www.ecircuitcenter.com/Circuits/op_pid/op_pid.htm

ResearchGate (Block Diagram Source).

https://www.researchgate.net/publication/338631554_Genetic_Algorithm_Tuned_PID_Controller_for_Process_Control

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