Lab-4

PID Tuning using Ziegler-Nichols Method

PID

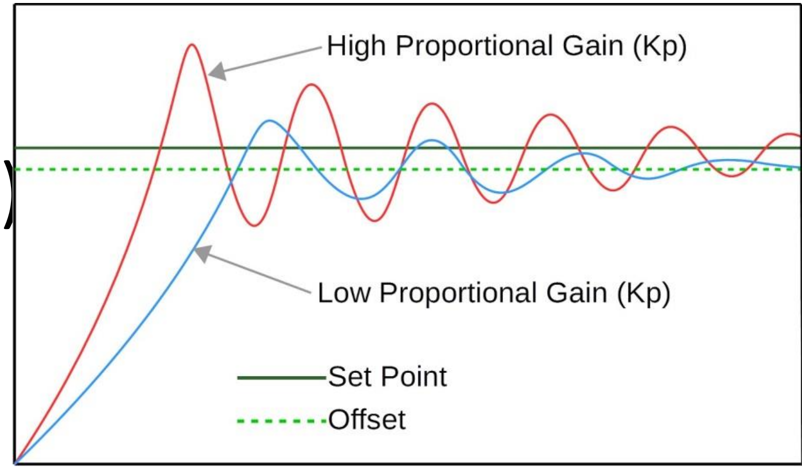
- What is PID Control?
- **PID** stands for **Proportional–Integral–Derivative** control.
- It is the **most widely used feedback controller** in engineering and industry (applied in robotics, process control, automotive, aerospace, etc.).
- Goal: minimize the **error**

$$e(t) = r(t) - y(t)$$

- where r(t) is the reference (setpoint) and y(t) is the actual output.

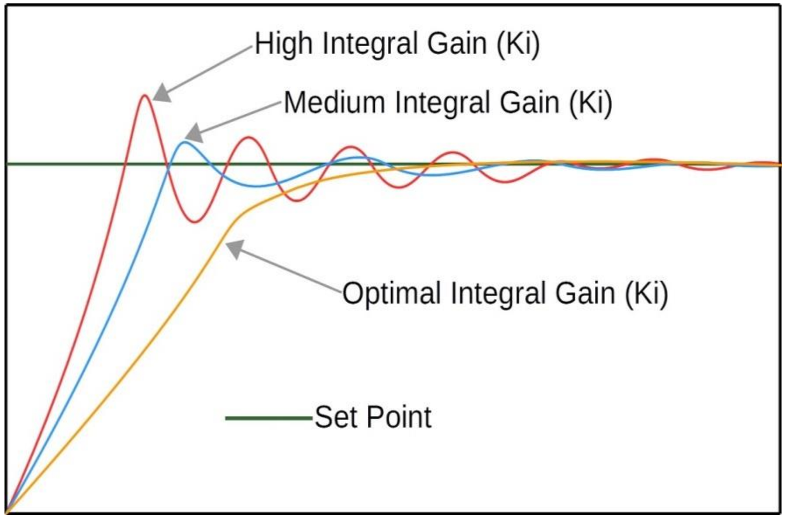
Proportional Controller

- **Advantages:** reduces rise time, speeds up response
- **Limitation:** cannot fully remove steady-state error
- **Proportional Gain (Kp):**
- ↓ Rise time (faster response)
- ↑ Overshoot
- ↑ Oscillations
- Small effect on steady-state error



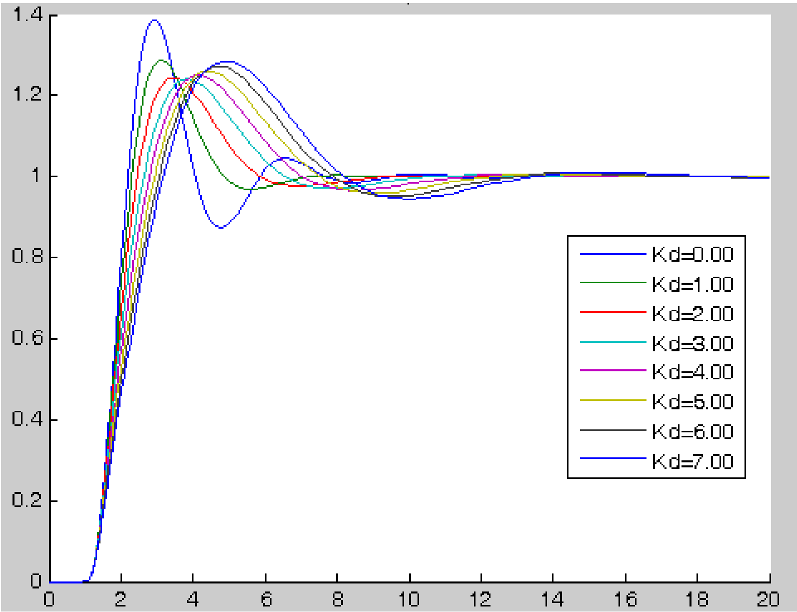
Integral Controller

- **Advantages:** eliminates steady-state error
- **Limitation:** too much →Slow response, oscillations, instability
- Eliminates steady-state error
- ↓ Rise time slightly
- ↑ Overshoot
- ↑ Settling time (system takes longer to stabilize)
- May reduce stability if too high



Derivative Controller

- **Advantages:** improves damping, reduces overshoot, improves stability
- **Limitation:** amplifies high-frequency noise
- **Derivative Gain (Kd):**
- ↑ Stability (adds damping)
- ↓ Overshoot
- ↓ Settling time
- Minimal effect on rise time
- Sensitive to noise



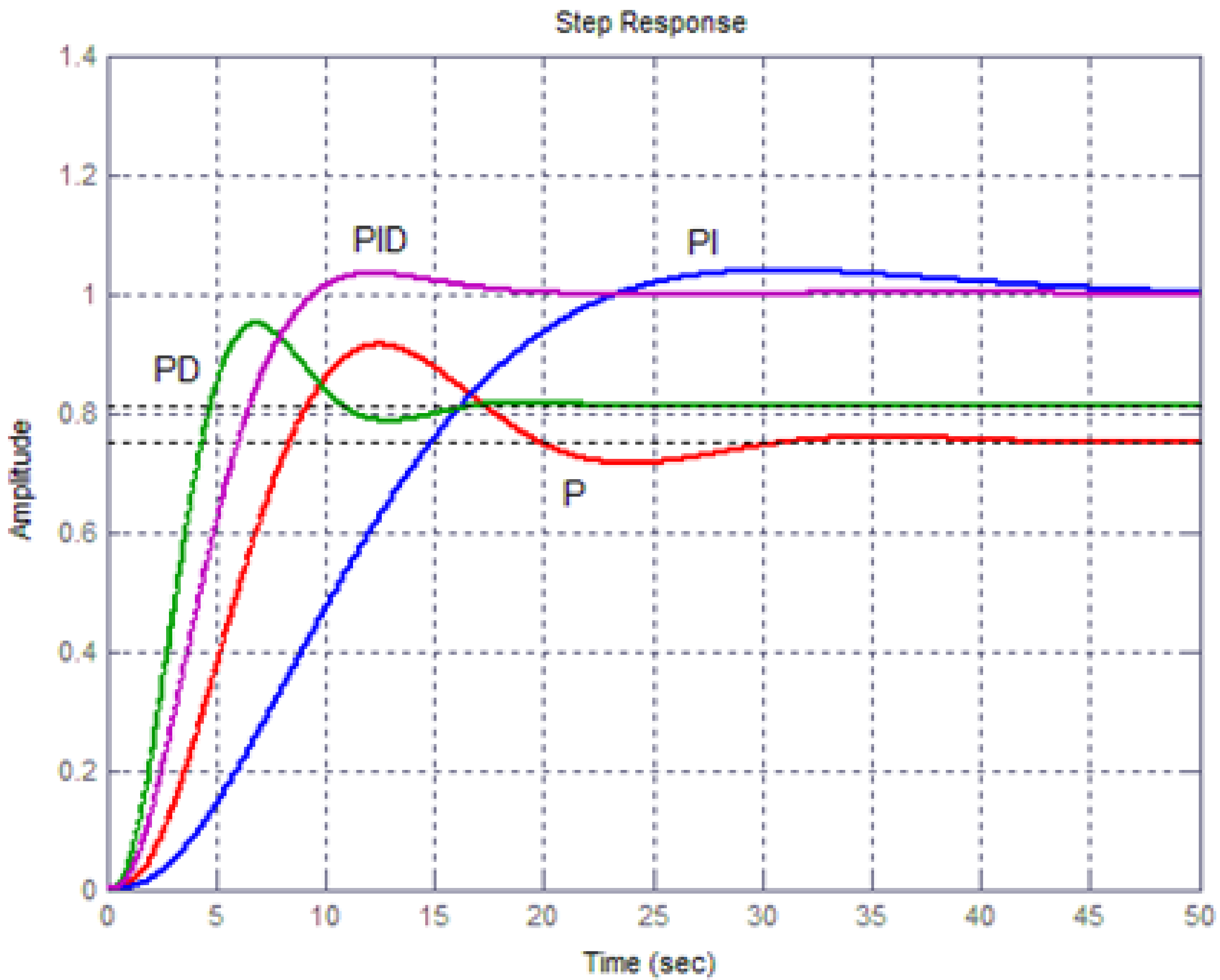
How to manage each performance metric:

- **If rise time is too slow →** increase Kp.
- **If overshoot is too high →** reduce Kp or increase Kd.
- **If settling time is too long →** increase Kd, but not too much.
- **If steady-state error exists →** increase Ki.

PK, PI, PD

Parameter	Rise Time	Overshoot	Settling Time	Steady-State Error	Stability
K_p	Decrease	Increase	Small Change	Decrease	Degrade
K_i	Decrease	Increase	Increase	Eliminate	Degrade
K_d	Minor Change	Decrease	Decrease	No Effect	Improve if K_d small

Response after Controller



Ziegler–Nichols

- The **Ziegler–Nichols (ZN) method** is a classical empirical procedure for tuning PID controllers. It provides systematic formulas for setting controller gains.
- Set controller to **P-only mode** ((K_i = 0, K_d = 0)) Apply a proportional gain (K_p) and close the loop.

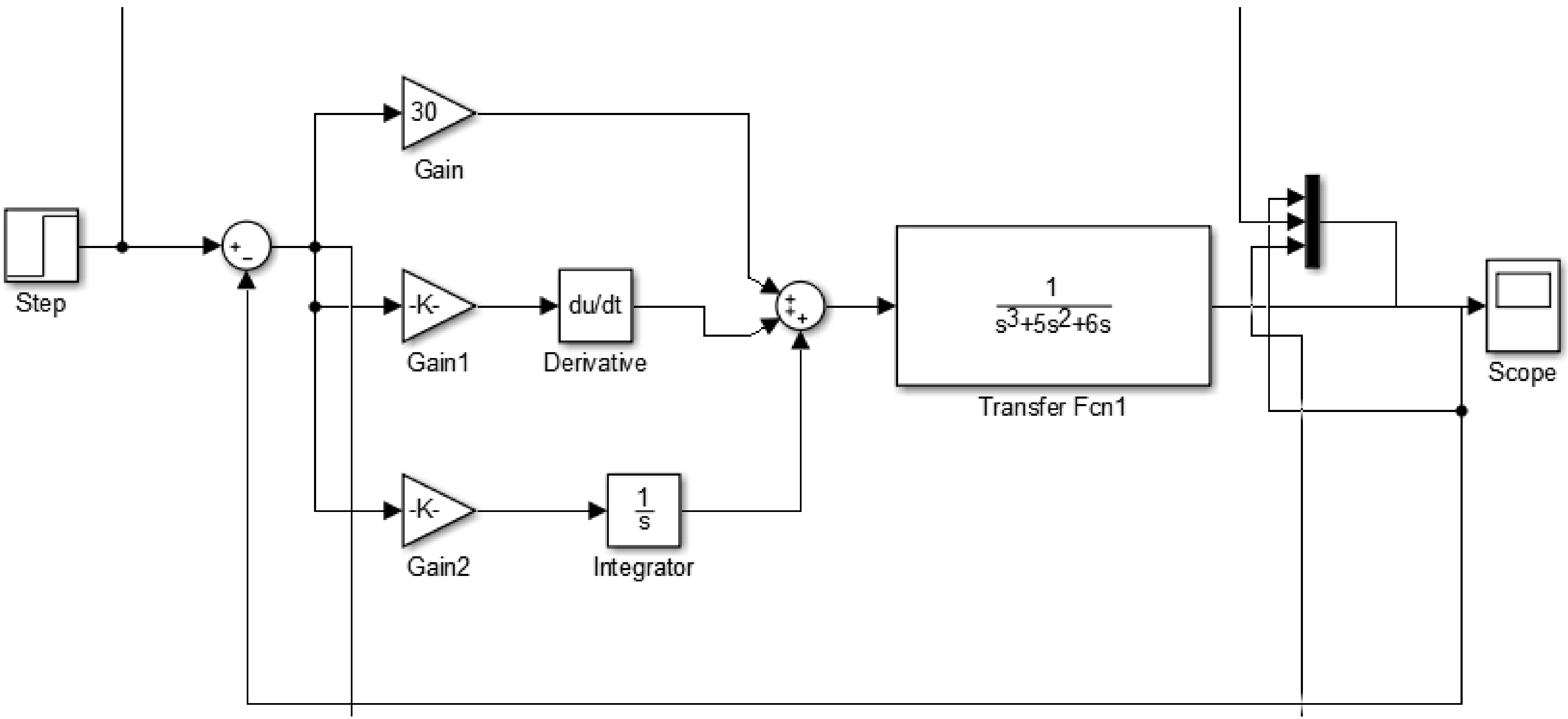
Ziegler–Nichols

- Increase (K_p) until the system output exhibits **sustained oscillations**. Record: **Ultimate Gain** ((K_u)) → the proportional gain at which oscillations first occur.
- **Ultimate Period** ((T_u)) → oscillation period at (K_u).

Ziegler–Nichols

Control Type	K_p	T_i	T_d
P	$0.5K_u$	–	–
PI	$0.45K_u$	$0.80T_u$	–
PD	$0.8K_u$	–	$0.125T_u$
classic PID[2]	$0.6K_u$	$0.5T_u$	$0.125T_u$
Pessen Integral Rule[2]	$0.7K_u$	$0.4T_u$	$0.15T_u$
some overshoot[2]	$0.3\bar{3}K_u$	$0.50T_u$	$0.3\bar{3}T_u$
no overshoot[2]	$0.20K_u$	$0.50T_u$	$0.3\bar{3}T_u$

PID in Simulink



RLC

Controller	Transfer Function	Components Used
P	(K_p)	Resistors (R)
I	(K_i/s)	Capacitors (C)
PI	(K_p + K_i/s)	Resistors + Capacitors (parallel feedback)
PD	(K_p + K_d s)	Resistors + Capacitors (series feedback)
PID	(K_p + K_i/s + K_d s)	Resistors + Capacitors (combined RC networks)

- **Op-Amps** are the core building block
- **Resistors (R)** → proportional control
- **Capacitors (C)** → integration & differentiation
- PID = combination of all