ANGLIA RUSKIN UNIVERSITY

FACULTY OF ENGINEERING AND BUILT ENVIRONMENT

MSC. ELECTRONIC/ELECTRICAL ENGINEERING

INDUSTRIAL PROCESS CONTROL

(MOD009172)

TECHNICAL REPORT

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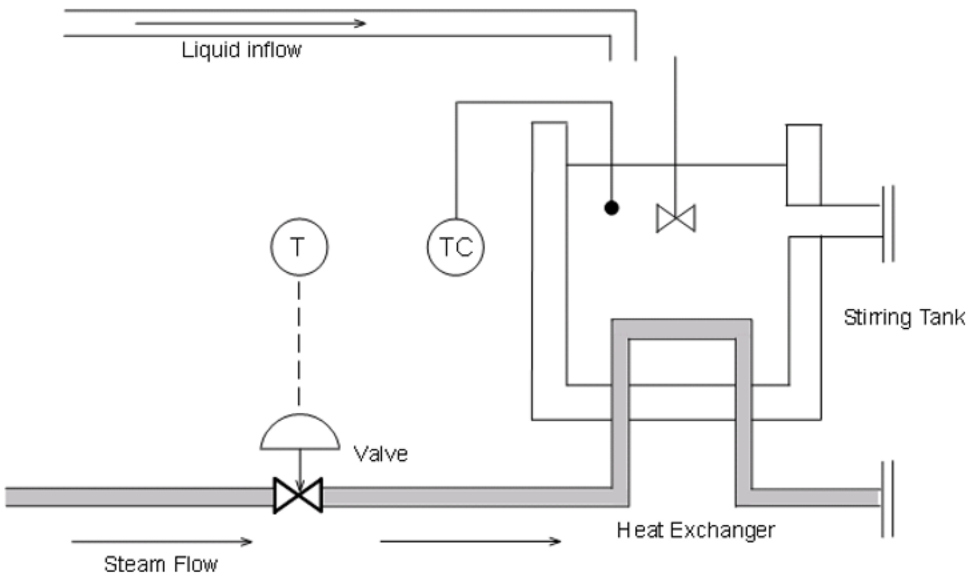
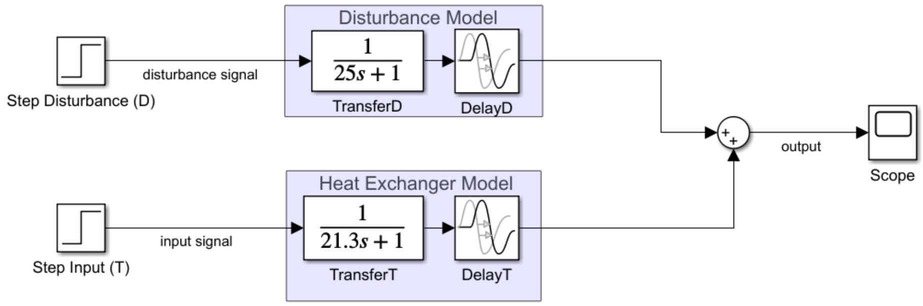
The Open Loop Process

Description



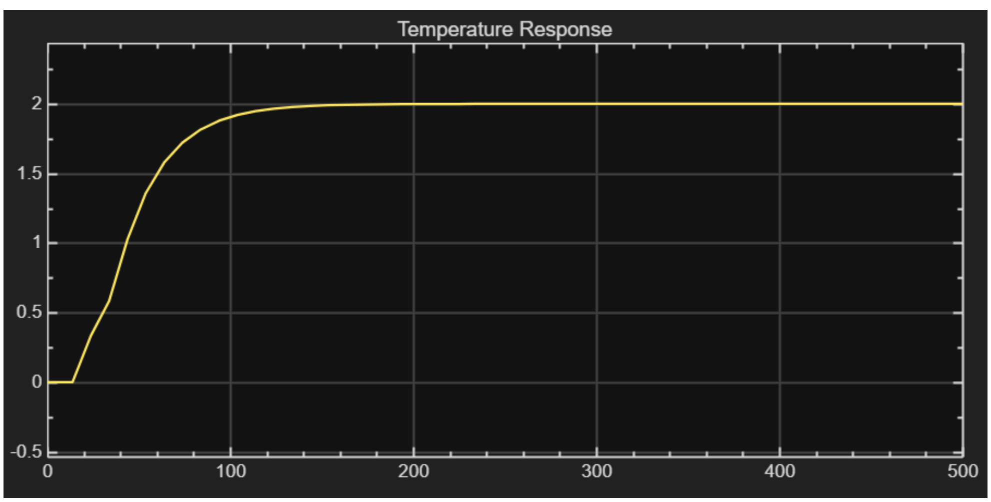
This system models a process consisting a heat exchanger and disturbance path, both identified as a first-order system with dead time. The heat exchanger shows the relationship between heater input voltage and outlet temperature, while the disturbance path represents external thermal effects. With no feedback, the outlet temperature is determined only by the applied input and disturbance, with no correction. This structure makes known thermal behaviour where heat transfer and fluid transport introduce slow dynamics, and time delays due to thermal inertia and lag.

Modelling in Simulink



The process was implemented as the sum of two independent first-order plus dead-time (FOPDT) blocks. Unit step were applied to both the manipulated input and the disturbance. Each path used a Transfer Fcn block of the form $1/(\tau s + 1)$, with time constants of 21.3 s (process) and 25 s (disturbance). The Transport Delay block added had delays, 14.7s and 35s. The outputs were summed and waveforms on a Scope over a 500 s simulation.

Response Characteristics

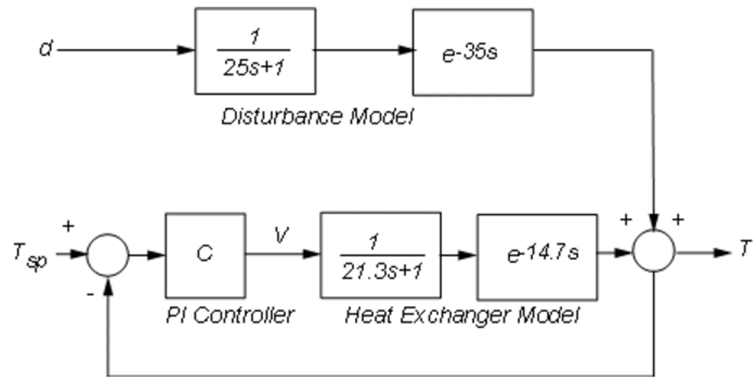


The response is stable, and well-damped, consistent with first-order behaviour. A dead time of 14.7s comes before the rise. The output settles at approximately 2.0 due to unity steady-state gains in both paths under unit steps. Rise time (10–90%) is about 62 s and settling time (±2%) about

120s. With no feedback, disturbances directly shift the output, making open-loop operation predictable and error prone.

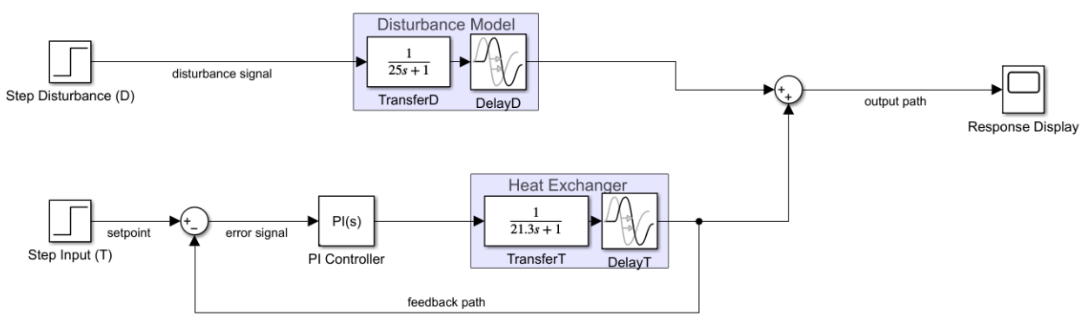
Feedback Control

Description



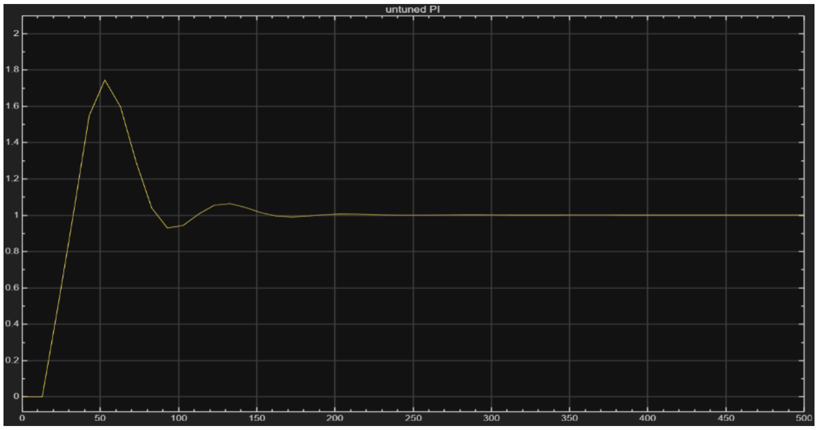
A PI controller is introduced to regulate the heat-exchanger outlet temperature. The measured temperature is compared with the setpoint to generate an error signal, which the controller converts into the heater input. The heat exchanger and disturbance dynamics are unchanged from the open-loop model, but the feedback loop enables setpoint tracking and automatically reduces the impact of disturbances, improving regulation.

Modelling in Simulink



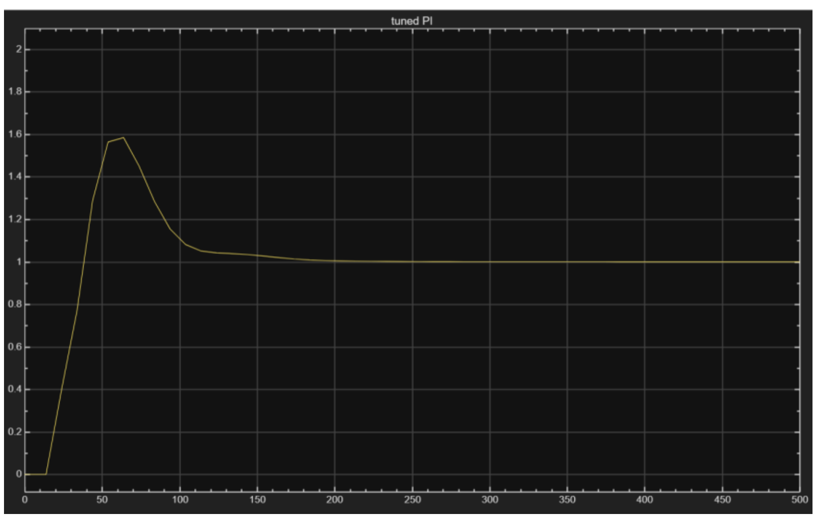
The open-loop model was closed by adding a feedback path. A Sum block forms the control error. The error is fed into a PI Controller block, whose output drives the heat-exchanger $\frac{1}{21.3s+1}$with a 14.7 s delay. The disturbance path $\frac{1}{25s+1}$with a 35 s delay is kept and summed with the process output. The resulting temperature response is displayed using a Scope.

Untuned PI Controller



The untuned PI controller is more aggressive and less damped. After dead time, the output rises rapidly but exhibits a large overshoot (approximately 70–75%), followed by an undershoot and damped oscillations. Settling time increases to 180–200s, although steady-state error is still removed by integral action. This illustrates how poor PI tuning can significantly degrade transient performance and stability margins.

Tuned PI Controller (ITAE)



This tuned PI gives a response that's quick and well-damped. After 14.7s, temperature rises with a time of about 30s. There is minimal overshoot(6-8%), then the response settles at its setpoint. The settling with the ±2% band happens at about 100-120s with no continued oscillations. Integral action removes steady-state error.

ITAE Tuning (Formula and Index)

ITAE (Integral of Time-weighted Absolute Error) is defined as $\int_0^{\infty} t \mid e(t) \mid dt$, penalising errors that persist and therefore discouraging long settling times and oscillations. Applying ITAE-based PI tuning for the FOPDT model (K=1, τ=21.3 s, L=14.7 s) produced $\boldsymbol{K_p = 0.8231}$and $\boldsymbol{K_i = 0.0354}$ (Ti=23.25 s). Performance comparison using the ITAE index gave **582.4 (tuned)** versus **1028 (untuned)**. In Simulink, the index was implemented by forming $\mid e(t) \mid$, multiplying it by time (Clock), integrating, and reading the final value.

The heat exchanger was modelled as a first-order plus dead-time (FOPDT) system:

$$G(s) = \frac{Ke^{-Ls}}{\tau s + 1}$$

with parameters $K = 1$, $\tau = 21.3$ s, and $L = 14.7$ s.

Using the ITAE (Integral of Time-weighted Absolute Error) PI tuning correlations:

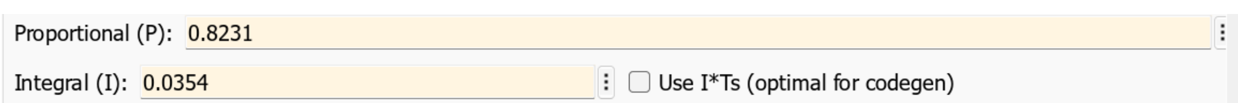
Proportional Gain: $K_p = \frac{0.586}{K}\left(\frac{L}{\tau}\right)^{-0.916}$

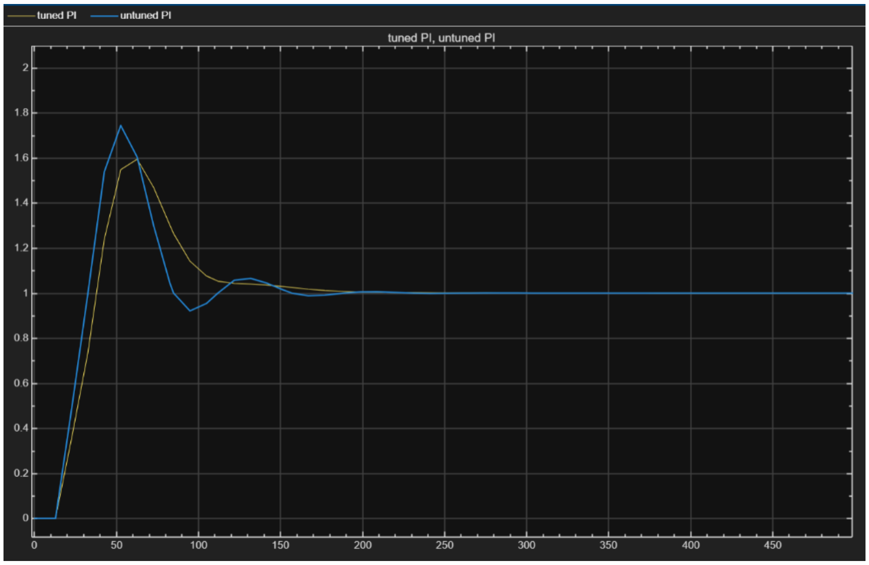
Integral Time: $T_i = \frac{\tau}{1.03 - 0.165(L/\tau)}$

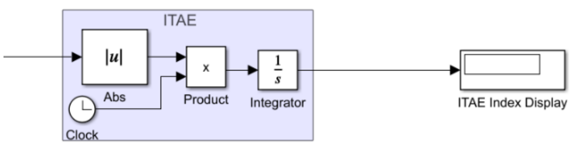
Integral Gain: $K_i = \frac{K_p}{T_i}$

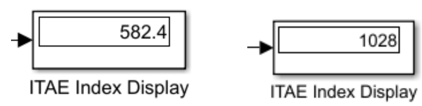
Substituting the process parameters (L/τ=0.6901) gives:

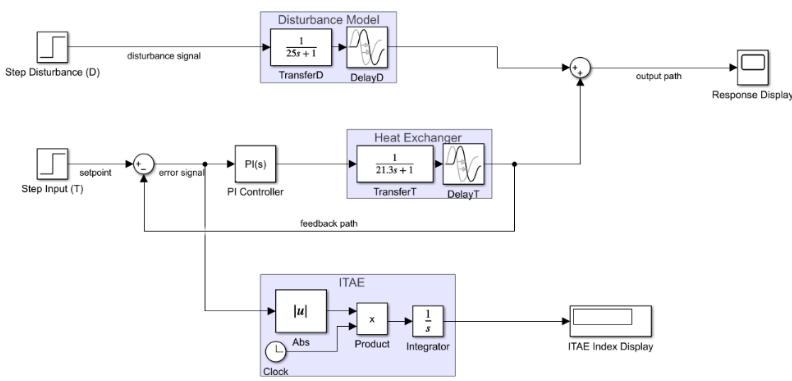
Kp = 0.8231, Ti = 23.25s, Ki = 0.0354




tuned PI
untuned PI
tuned PI, untuned PI
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
400
450

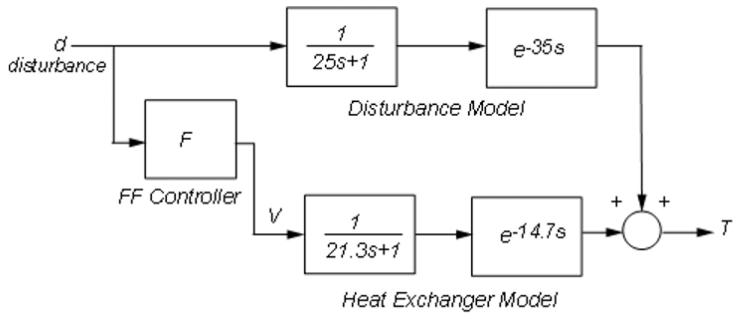

ITAE
|u|
Abs
x
Product
1/s
Integrator
Clock
ITAE Index Display


582.4
ITAE Index Display
1028
ITAE Index Display


Step Disturbance (D)
disturbance signal
Disturbance Model
1/(25s + 1)
TransferD
DelayD
output path
Response Display
Step Input (T)
setpoint
error signal
PI(s)
PI Controller
Heat Exchanger
1/(21.3s + 1)
TransferT
DelayT
feedback path
ITAE
|u|
Abs
x
Product
1/s
Integrator
Clock
ITAE Index Display

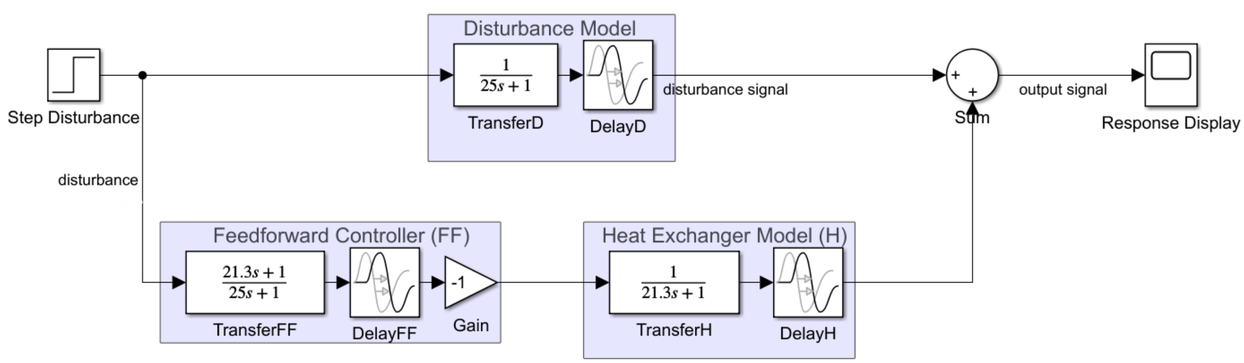
Feedforward Control

Description



Feedforward control rejects measurable disturbances by compensating for their effect before they appear at the output. The disturbance is passed through a feedforward controller that counteracts the disturbance dynamics using an approximate inverse of the process model. Unlike feedback, it does not use output error and therefore acts from the disturbance signal. When the model and delay matching are accurate, the disturbance impact on outlet temperature is reduced.

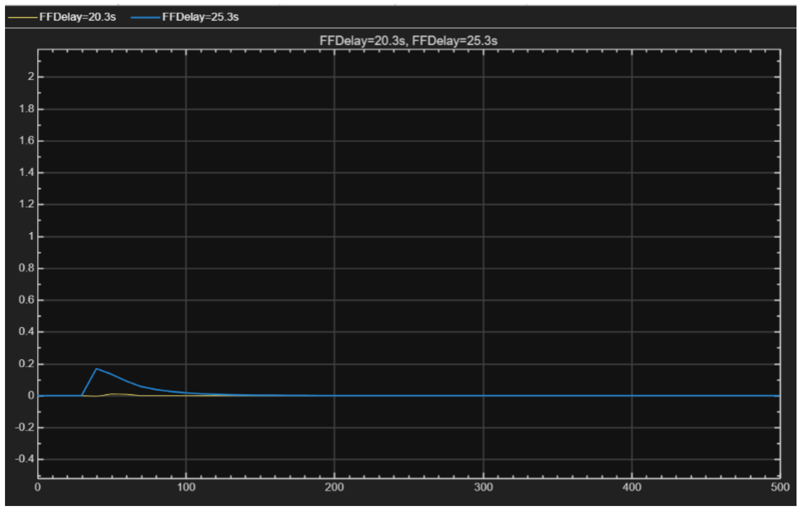
Modelling in Simulink



A feedforward path was added to the open-loop process. The disturbance passes through the disturbance model $\frac{1}{25s+1}$ with a 35 s delay and through a feedforward controller $(21.3s + 1)/(25s + 1)$ with an additional delay. A -1 gain guarantees cancellation. The feedforward output energises the heat-exchanger $\frac{1}{21.3s+1}$ with a 14.7s delay, and the outputs summed and shown on the Scope.

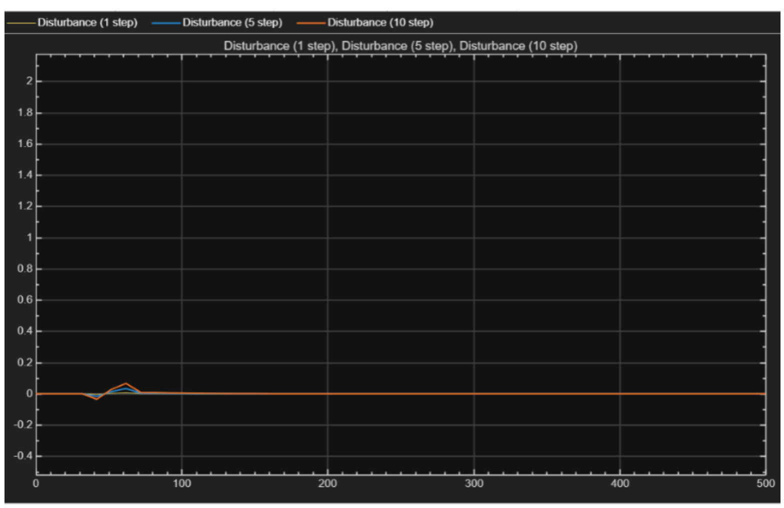
Response Characteristics

Varying delay



With FFDelay = 20.3s (corresponding with the delay difference), disturbance cancellation is near-ideal, only a very small transient occurs, and the output returns quickly to zero with no steady-state error. Increasing FFDelay to 25.3s introduces a larger residual peak because compensation arrives late, degrading transient rejection though steady-state offset remains zero.

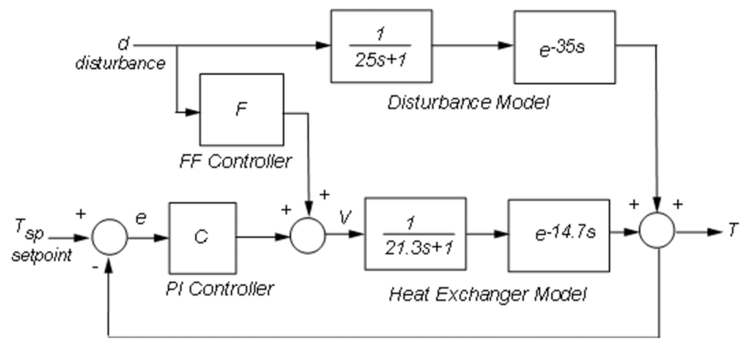
Varying the step disturbance



For unit, 5, and 10-step disturbances, the signal stays close to zero, but there is increase in peak deviation, indicating near-linear behaviour. Feedforward reduces disturbances, but residual transients and model mismatch motivate adding feedback in practice.

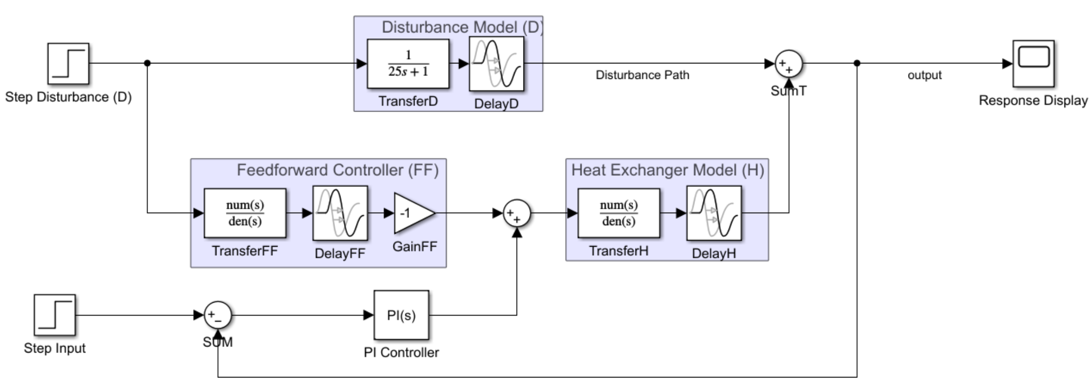
Combined Feedback/Feedforward Control

Description



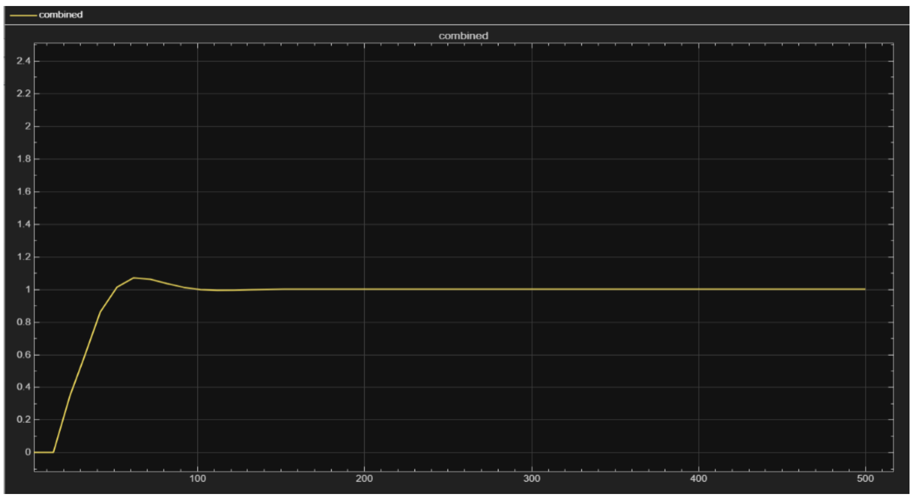
This setup integrates feedforward disturbance compensation with PI feedback to achieve proper temperature regulation. Feedforward acts on the measured disturbance to cancel it before it reaches the output, while PI feedback removes residual error caused by delay mismatch and unmeasured disturbances. This structure combines fast disturbance rejection(feedforward) with stability and zero steady-state error(feedback).

Model Development in Simulink



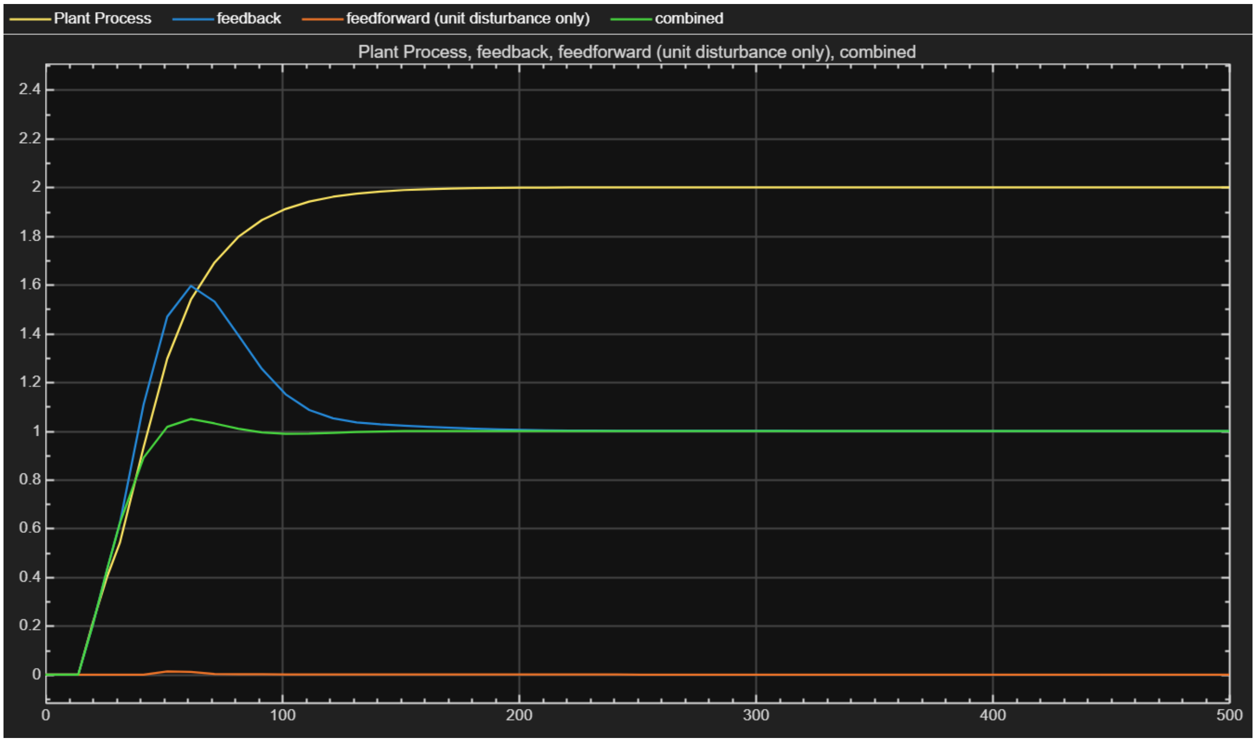
The Simulink model superimposes the feedback and feedforward paths. A Step block generates the setpoint and a Sum block forms the error. The error is processed by the PI, and its output is summed with the feedforward control signal. The input disturbance splits into two: the disturbance model $\frac{1}{25s+1}$ with a 35s delay, and the feedforward controller with additional delay and gain, -1. The combined control signal drives the heat-exchanger model $\frac{1}{21.3s+1}$with a 14.7s delay. Process and disturbance outputs are summed and demonstrated on a Scope.

Response Characteristics



The response is stable and well-damped. After an initial dead time of ~15, the temperature rises smoothly to the setpoint with a 10–90% rise time of ~30–40 s. A small peak of 1.08 (≈8% overshoot) is observed, followed by a smooth decay without sustained oscillations. The output enters the ±2% band by ~100–120 s and converges to 1.0, confirming zero steady-state error due to integral action. Feedforward reduces disturbance load on the feedback loop, improving regulation under disturbance. This structure provides accurate setpoint tracking from feedback, while feedforward reduces the disturbance burden on the feedback loop, improving overall regulation in disturbances' presence.

Comparing all Control Systems



Observations

1. **Open loop:** slow response; final value ≈2 since input and disturbance add directly.
2. **Feedback:** zero steady-state error, but larger overshoot and longer settling when poorly tuned.
3. **Feedforward:** strong disturbance rejection but cannot track setpoint changes.
4. **Combined:** best overall performance, fast tracking, low overshoot, and strong disturbance rejection.

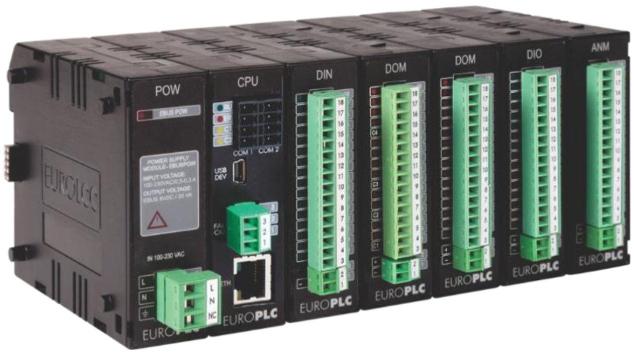
Table 1: Comparative Response Characteristics

System	Final Value	Rise Time (10–90%)	Peak Value	Overshoot (%)	Settling Time (±2%)	Steady-State Error
Open-Loop Plant	≈ 2.0	≈ 80–100 s	≈ 2.0	0%	≈ 150–180 s	Large (uncontrolled)
Feedback (PI)	≈ 1.0	≈ 30–35 s	≈ 1.55–1.60	≈ 55–60%	≈ 150–180 s	≈ 0
Feedforward Only	≈ 0.0	N/A	≈ 0.02–0.03	N/A	≈ 80–100 s	≈ 0 (disturbance only)
Combined FF + FB	≈ 1.0	≈ 30–40 s	≈ 1.05–1.08	≈ 5–8%	≈ 100–120 s	≈ 0

SCADA, DCS, and PLCs in the Process Control Industry

Modern process plants (oil and gas, chemicals, power, water, pharmaceuticals) depend on industrial control systems to maintain safe, stable, and economical operation. While PLCs, DCS, and SCADA all support measurement, control, and operator interaction, they are optimised for different control layers and operating contexts, with distinct performance and cybersecurity implications. A useful framing is PLCs for real-time equipment control, DCS for plant-wide process control inside a facility, and SCADA for supervisory oversight of distributed systems.

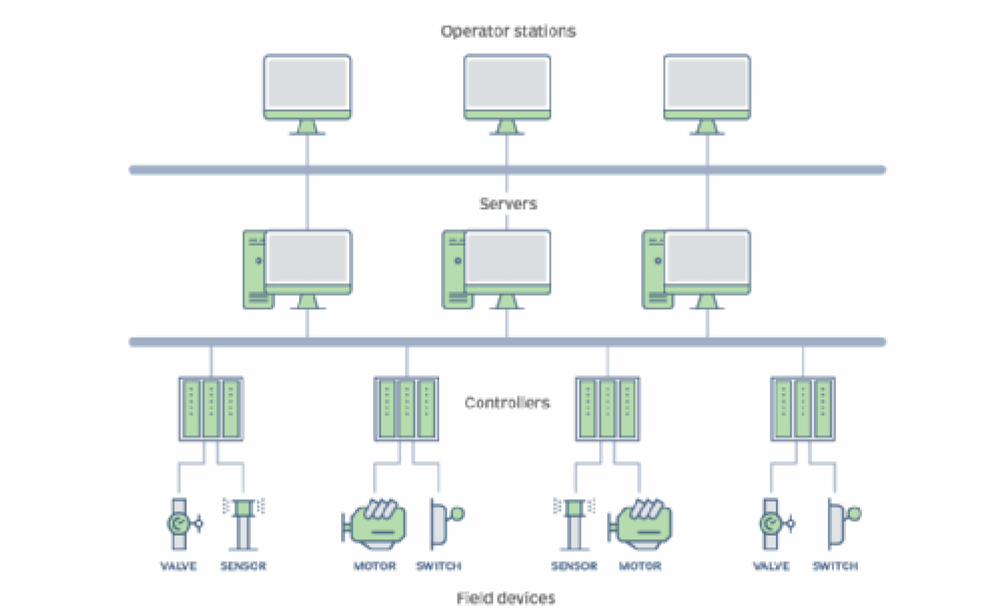
PLCs: Equipment-Level Control



A PLC is an industrial computer that executes logic predictably (read inputs, perform logic, write outputs). It is well-suited to fast interlocks, sequencing, and local PID where required.

Role in process control: Packaged unit operations; discrete sequencing/interlocks, safety-adjacent automation.
Main advantage: Speedy and deterministic proximity to equipment (e.g., trips, motor control).
Main disadvantage: does not involve plant-wide operations without higher layers (integrated alarms, coordination, trending).
Key risks: Faults of hardware or programming errors can stop control or make the process unsafe, more prone to cyber-attacks as connectivity/remote access expands

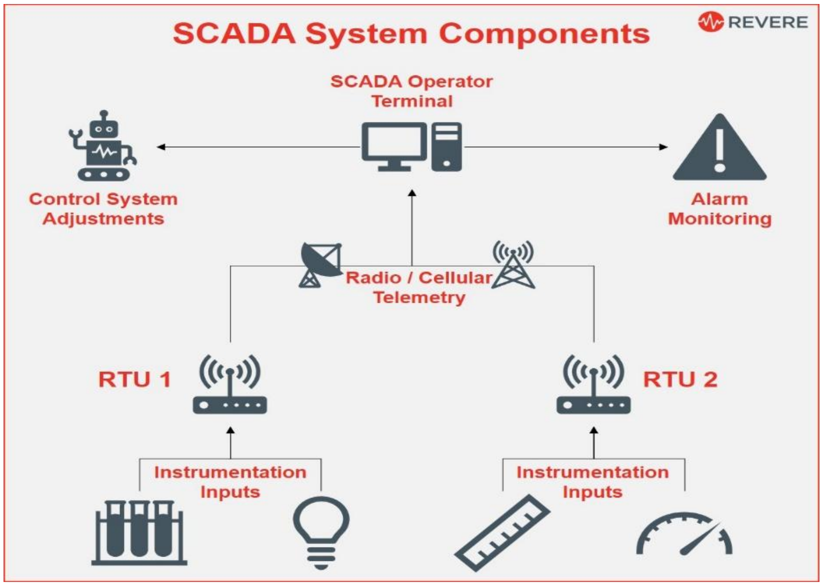
DCS: Integrated Plant-Wide Process Control



A DCS is an integrated environment for continuous/batch control, typically combining distributed controllers, HMIs, engineering tools, alarm management, trending, and often a historian. It emphasises stability, operational consistency, and maintainability for complex process.

Role in process control: large numbers of PID loops, coordinated strategies (feedforward, constraints, batch), unified operator workflows, plant-wide visibility.
Main advantage: tight integration and consistent standards (alarms, graphics, engineering), reducing operator error in high-hazard contexts.
Main disadvantage: higher cost and vendor lock-in.
Key risks: A failure of DCS network can disrupt large sections of the plant at the same time, lifecycle–cybersecurity tension due to availability and vendor patch/compatibility limits.

SCADA: Supervisory Monitoring and Control



SCADA focuses on telemetry, event/alarm visibility, and supervisory commands for geographically distributed assets (pipelines, water networks, remote sites). Local controllers (PLCs/RTUs) typically perform fast control, while SCADA aggregates data and coordinates oversight.

Main advantage: scalable supervision of many remote locations.
Main disadvantage: dependence on communications performance, not intended for high-speed closed-loop control.
Key risks: expanded attack surface from wide-area connectivity and remote access.

How They Work Together in Real Plants

Commonly, PLCs control discrete logic, DCS runs the facility's core process control and operator interface, and SCADA supervises remote assets supporting or feeding the plant. Clear authority and consistent alarming/time synchronisation are essential to avoid gaps and overlaps.

Security and Risk Management Across All Three

Selecting PLC/DCS/SCADA varies the risk profile rather than eliminate the risk. Best practice stresses segmentation, strong access control and change management, secure remote access, and disciplined backup/restore and recovery testing, aligned with lifecycle-based ICS security guidance (e.g., ISA/IEC 62443).

Conclusion

Choose **PLCs** for specific equipment control, DCS for integrated plant-wide process control, and **SCADA** for supervisory control of distributed systems.

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