

BELLTES ACADEMY

Advanced Process Control & Industrial Automation

A Comprehensive Technical Guide to Feedforward, MPC, and Reactor Case
Studies

Written by Belltes Khoza

1. Model Predictive Control (MPC)

Model Predictive Control (MPC) is the standard advanced control methodology utilized in high-variable modern chemical facilities. Unlike legacy PID single-loop configurations, MPC treats plant automation as a multi-variable optimization matrix over an explicitly defined time window.

1.1 The Receding Horizon Principle

MPC operates by looking into the future using an integrated dynamic model of the facility process. At each execution interval, the controller solves an open-loop optimization objective function to minimize deviations from a target trajectory over a specified prediction horizon.

- **Prediction Horizon (P):** The total duration into the future over which the controller evaluates the process responses.
- **Control Horizon (M):** The number of future manipulated variable adjustments calculated at the current step. To stabilize calculations, M is kept smaller than P.
- **Receding Window Implementation:** Although an optimal sequence of M future moves is calculated, only the very first change is implemented. At the next sampling interval, new sensor telemetry updates the state vector, and the entire optimization is shifted forward in time.

1.2 Mathematical Formulation & Objective Functions

The standard cost function J that the controller minimizes at every step can be mathematically represented as:

$$J = \sum_{i=1}^P Q_i [y(k+i|k) - r(k+i)]^2 + \sum_{j=1}^M R_j [\Delta u(k+j-1)]^2$$

Where $y(k+i|k)$ represents the predicted value of the controlled variables, $r(k+i)$ stands for the target profile trajectory, Δu represents the calculated valve adjustments, and Q and R represent weighting matrices that balance target tracking accuracy against aggressive physical wear on the control valves.

2. Feedforward Architecture & Dynamic Compensation

Feedback loops must wait for an error to manifest before taking remedial action. Feedforward architecture bypasses this limitation by measuring incoming disturbances directly and preempting their effect on the process.

2.1 Static vs. Dynamic Feedforward Compensation

Static feedforward architectures apply simple steady-state gain ratios to change valve positions. This approach fails when the disturbance propagation path has a different time constant than the manipulated variable path. Dynamic feedforward uses lead-lag transfer networks to resolve this phase lag mismatch.

2.2 Ideal Feedforward Transfer Function Derivation

Consider a system where a controlled variable is influenced by a disturbance path $G_d(s)$ and a control path $G_p(s)$. The net process equation is:

$$Y(s) = G_p(s)U(s) + G_d(s)D(s)$$

To ensure the disturbance creates zero net deviation in the output ($Y(s) = 0$), we substitute and isolate the feedforward controller expression $G_{ff}(s) = U(s) / D(s)$:

$$G_{ff}(s) = - \left[G_d(s) / G_p(s) \right]$$

If the disturbance path responds faster than the control path, the resulting feedforward function requires a pure derivative predictive term, which must be mathematically smoothed using a low-pass filter to prevent valve chatter.

3. Industrial Reactor Control Case Study

To contextualize these concepts, we analyze an exothermic Continuous Stirred-Tank Reactor (CSTR) where a zero-order exothermic reaction takes place. Uncontrolled temperature spikes can trigger thermal runaway.

Control Strategy	Target Controlled Variable	Manipulated Element	Primary Benefit	
Cascade Loop	Internal Reactor Temp	Cooling Jacket Flow	Rejects upstream coolant utility line pressure variations.	<ParagraphStyle 'Body_C
Dynamic Feedforward-Feedba	Internal Reactor Temp	Cooling Jacket Flow	Adjusts coolant instantly when raw feed inlet temperature spikes.	<ParagraphStyle 'Body_C
Model Predictive Control (MPC)	Reactor Temp & Product Concentration	Coolant Flow & Inlet Feed Pump Speed	Maximizes conversion throughput while strictly bounding thermal safety zones.	<ParagraphStyle 'Body_C

By implementing MPC alongside dynamic feedforward compensation, the reactor operating margin can safely run closer to upper chemical limits without tripping emergency safety interlocks.