Plant-wide on-line dynamic modeling with state estimation: Application to polymer plant operation and involvement in trajectory control and optimization.

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• Dow and its Polystyrene business
• Model based applications as enabler of the business strategy elements
• Advanced Process Information
  • on-line dynamic model with state estimation
  • application examples
  • implementation status
• Trajectory control within IMPACT project
• Trajectory optimization within IMPACT project
• Future Directions
Dow is the global leader in Polystyrene with around 20 plants worldwide.

Consequently:
- consistent product quality
- maximizing unit production
- leveraging of standardization and operating discipline

are key business strategy elements.

Dynamic modeling with state estimation has proven to be a powerful enabler in achieving these objectives.
Polystyrene solution process

Styrene + Solvent

Styrene
Solvent
(Initiator)

Rx Rx Rx

Polystyrene
Implementation using Aspen SEM and Aspen Custom Modeler

- Aspen SEM is a general purpose non-linear dynamic data reconciliation solver using an Extended Kalman Filter linked with ACM for model predictions and time varying linear state space models.
- Main applications:
  - continuous, real-time estimation of relevant process variables that are unmeasureable or infrequently measured
  - Rejection of unknown disturbances and model deficiencies by adjusting parameters via introduction of stochastic states (disturbance model)
  - Look-ahead capability
  - Process monitoring and decision support tool – allow Data Reconciliation to be combined with Multivariate Statistical Process Control techniques for fault detection and diagnosis
  - Model Predictive Control
On-line dynamic modeling with state estimation

**PROCESS PLANT**

- Plant INPUTS
- Plant OUTPUTS
- **DCS**

**Model OUTPUTS**

- Integrate Dynamic Model
- Initialise Dynamic Model
- Linearisation Discretization
- Kalman Gain
- Kalman CORRECTIONS
- Kalman INNOVATIONS
- Model/Plant Mismatch

**Model PREDICTIONS**

**State estimation architecture**
Aspen SEM applications

• Particularly suited for:
  • Multi-Product Processes
  • Frequent and Significant Transitions
  • Frequent Unknown Disturbances
  • Steady-State approximations not valid
  • Batch Processes

• Different operating modes:
  • On-line real time with plant real-time database
  • Off-line faster than real time with historical data (MS Excel as repository)
  • Synchronized with ACM emulation model or with a control application (via dbase)
  • On-line emulation with plant database populated by an ACM virtual plant model

• Key building block for model based Process Information, Monitoring and Control systems
Applications for Polystyrene at Dow

- Increased production rates:
  - better understanding and timely information to plant operation
  - ability to relax some constraints with same reliability
- Reduced transition times and off-spec product:
  - staying longer on Grade A and moving faster to Grade B
  - no waiting for lab results in many cases
  - understanding and removal of limiting steps
- Preventing upsets:
  - look-ahead gives early warning leading to preventive action
  - estimates of unmeasured process variables are used to diagnose and decide how to address operational issues
- Dynamic reconciliation of recycle stream composition
On-line dynamic modeling with state estimation
Application example (1) : Process Inferentials

Measured and unmeasured components in a stream

On-line dynamic modeling with state estimation
Application example (2): Product Inferentials
Continuous property estimates with infrequent sampling

On-line dynamic modeling with state estimation
Application example (3): faster from prime to prime

Look-ahead prediction indicates “prime time”
On-line dynamic modeling with state estimation

Application example (4): troubleshooting
Relative behavior of PV estimates explains overshoot
On-line dynamic modeling with state estimation

Application example (5): off-line FTRT

Off-line study on the effect of KF updates on final product property
On-line dynamic modeling with state estimation

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• IMproved Polymer Advanced Control Technologies
• European Research Project (Eureka)
  • Belgium : ISMC, KU Leuven, Dow Belgium
  • The Netherlands : IPCOS, TU Delft, Dow Benelux

• Dow Scope : Feasibility of MPC and Trajectory Optimization applied to the Polystyrene process
  • Application on dynamic model of a Polystyrene plant
  • Design and simulate the application of a constrained multivariable controller for trajectory control
  • Design and execute trajectory optimization based on existing process model
  • Economic evaluation
Trajectory control

- Moving from one operating point to another following a best practice path
- Dealing with non-linearities through:
  - Delta mode configuration
  - Multiple linear models
On-line dynamic modeling with state estimation

Prioritized control

Class 0
- MV ROC constraints
- MV POS constraints

Class 1
- Requirement 1
- Requirement n

Freedom left?
- yes
- no

Class i
- Requirement 1
- Requirement n

Class last
- Minimize MV moves

LS Solution restricted by the solution of class 0
LS Solution restricted by the solution of class 0 to i-1

Importance
Safety
Quality
Productivity
Other ...

Project IMPACT: advanced control (2)
Project IMPACT: advanced control (3)

Related application with model based multivariable control using INCA:
Production rate increase for “on-aim” or “within specification” mode

Controller with around 10 MV/20 CV applied to simulation based plant emulation

On-line dynamic modeling with state estimation
Trajectory control example:
Following a best practice trajectory = history data for MV’s & CV’s

Disturbance

CV1 - Constraint

CV2 - Quality

CV3 - Productivity
Economically Optimal Grade Transitions

Objective = Maximize Added Value during a transition

\[ AV(T) = \int_0^T \sum_j price_j(t) \cdot \text{throughput}_j(t) \, dt - \int_0^T \sum_i \text{cost}_i(t) \cdot \text{feed}_i(t) \, dt \]
PathFinder, a tool for calculation of Economically Optimal Dynamic Grade Transitions

‘Find dynamic MV’s such that objective is optimized subject to process operation constraints (Off-line)’
**Economically Optimal Dynamic Grade Transitions**

**Fast (Off-Line) Trajectory Optimization**

1. **Process Model**
   - Smoothly Non Linear
   - Long Calculation Time

2. **Economic Objective**
   - Highly Non Linear
   - Short Calculation Time

**REPLACE WITH FAST LINEARIZED MODEL (SSQP)**

Typically: 10 Process model evaluations/Linearizations needed
On-line dynamic modeling with state estimation

Project IMPACT: Trajectory optimization (4)

SQP

SQP run on Linearized model + economic criterion

- Initial Trajectory
- Intermediate Result
- Final Trajectory

Check on Rigorous Model

Improved?

- No
- Yes

Derive New Linear Time Variant model

Adapt Trust Region
PathFinder applied to a validated rigorous model of a Dow polystyrene production facility at Tessenderlo, Belgium

- 14 Manipulated Variables with 13 move times = 182 Degrees of freedom
- Absolute Boundaries on all MV’s
- Rate of Change Constraints on 10 MV’s
- Path Constraints on 8 Process Variables
Example of result: Trajectory Optimization based on market situation

<table>
<thead>
<tr>
<th>Original</th>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price Onspec-Offspec Not Applicable</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Price Offspec-Styrene Not Applicable</td>
<td>Negative</td>
<td>Positive</td>
</tr>
</tbody>
</table>

Legend:
- Original
- Not Applicable
- High
- Negative
- Low
- Positive

Simulation based results
On-line dynamic modeling with state estimation
Future directions

• More model based advanced process information implementations and applications
• Real life application of transition control in a polymer plant
• Combined application of transition optimization and control
• Other area of particular interest:
  • Robust dynamic modeling for optimization and control applications
  • Real-time integrated dynamic optimization and control
  • Robust non-linear model predictive controllers
  • Non-linear model reduction
  • Operator training

• Related papers: