Degrees of Freedom Analysis of Economic Dynamic Optimal Plantwide Operation

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Motivation

Improvement of operation is an attractive option for the process industry to deal with increased competition. The economic performance of continuous as well as batch processes can be improved by dynamic optimization. The research focuses on two questions:

1. *How to frame dynamic optimization such that we can expect improved operation in an economic sense?*

2. *Does dynamic optimization with an economic objective utilize all Degrees Of Freedom (DOF)?*

Framework

The proposed framework is characterized by:

- An economic cost objective. So via the objective there is a *direct link* with real process economics.

- A plantwide system boundary that includes product tanks. A plantwide boundary avoids the need for *intermediate pricing*. The tanks offer *extra freedom* for dynamic improvement.

- A finite time horizon and constraints on product quantity and quality. This facilitates *integration with scheduling*.

The dynamic optimization problem is now given by:

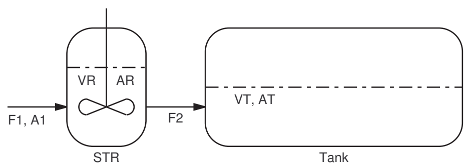
$$\min \text{cost}$$
$$\text{s.t.}\begin{cases}\text{process model}\\ \text{required quantity and quality}\\ \text{operational constraints}\end{cases}$$

Numerical experiments

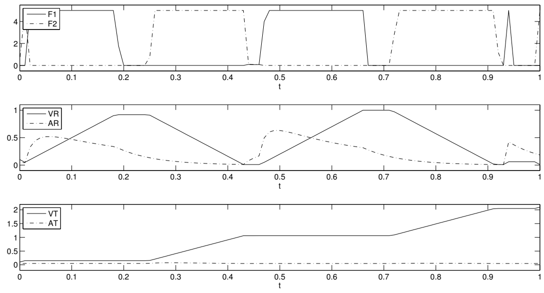
Two process systems were investigated:

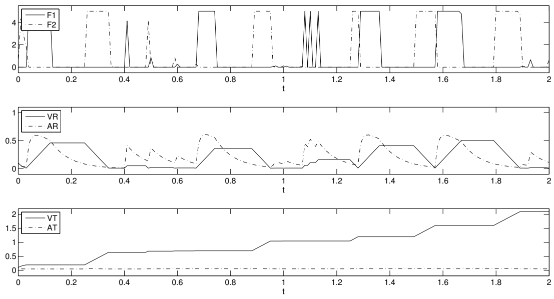
1. A Stirred Tank Reactor (STR) and a tank.

2. A Distillation Column (DC) and a tank.



For the STR and tank system the objective was to minimize the integrated value of (vF1 + VR), this objective reflects the operating costs. The dynamic optimization was solved using the simultaneous approach. The implementation was done in the algebraic language GAMS with CONOPT as solver. The results are shown for a time horizon of 1.0 and 2.0 hours.



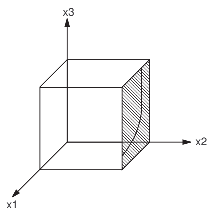


For a short time horizon the solution is almost periodic (two batches!). For a long horizon the results seem arbitrary; this can be explained by the existence of *multiple solutions*.

In the case of the DC and tank system the optimal trajectories feature constant ratios (boil-up over feed and reflux over feed). But also in this case the optimization results in multiple solutions.

Multiple solutions are caused by the combination of a sparse linear objective and linear inequality constraints. This can be illustrated by a simple optimization problem:

$$\max_{x1,\,x2,\,x3} x2$$
$$s.t.\begin{cases}x1x3 = 0.5\\ 0 \le x1 \le 1\\ 0 \le x2 \le 1\\ 0 \le x3 \le 1\end{cases}$$



Conclusions and future work

The framework produces valuable results. However normally it does not utilize all DOF. This opens the possibility to do further optimization.

Future work will focus on the use of *hierarchical optimization*. In the first stage the best economic performance is determined by the proposed framework. In the second stage a unique solution is selected from the multiple solutions based on an operational preference.

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