Economic Nonlinear Model Predictive Control for Flexible Operation of a Reaction-Separation-Recycle Process

Mohammad El Wajeh,a Adel Mhamdi, a Alexander Mitsos, a,\*

aRWTH Aachen University, Process Systems Engineering (AVT.SVT), Aachen, Germany

\*amitsos@alum.mit.edu

Abstract

Economic nonlinear model predictive control (eNMPC) can enable flexible and economically optimal process operation. We apply eNMPC within a virtual environment to an electrified reaction-separation-recycle process actively participating in real-time electricity markets, a subprocess of biodiesel production detailed in our recent work (https://arxiv.org/abs/2308.09537). Employing a mechanistic dynamic model that serves as both the controller model and plant surrogate, we perform a closed-loop case study spanning a 24-hour period with historical electricity prices. The eNMPC strategy results in energy cost savings exceeding 28% compared to optimal stationary operation, yielding similar results to offline dynamic optimization, all while maintaining real-time feasibility.

**Keywords**: Model predictive control, Demand-side management, Optimal control

* 1. Introduction

One effective approach for achieving flexible and economically optimal operation of chemical processes is economic nonlinear model predictive control (eNMPC) (Amrit et al., 2013). eNMPC involves solving a dynamic optimization (DO) problem with an economic objective function directly within the controller while considering process models and operational constraints. While researchers have successfully applied eNMPC in various applications, its potential for realizing demand-side management in electrified chemical processes involving reaction, separation, and recycle (RSR) components remains underexplored in the literature. We apply eNMPC in silico to an electrified RSR process, specifically focusing on a simplified version of the biodiesel production subprocess in El Wajeh et al. (2023). We examine a typical demand-response scenario and utilize the same model for both the eNMPC controller and the plant surrogate. For a more comprehensive understanding of the process description and modeling, see El Wajeh et al. (2023). The RSR process flowsheet is illustrated in Figure 1.

* 1. eNMPC Strategy

We implement the eNMPC strategy by solving online DO problems with a sampling time of 15 minutes over one day. We minimize the process operating cost while penalizing the control moves and enforcing operational constraints on product purities and level limits. To maintain computationally tractable DO, the control and prediction horizons extend to 10 and 12 hours, respectively. For each optimization iteration, we discretize the controls and constraints at 30-minute and 15-minute intervals, respectively. We implement the model in Modelica and use DyOS (Caspari et al., 2019) to solve the DO problems.

Figure 2. Production rate and electricity price profiles.

Figure 1. Simplified RSR biodiesel subprocess flowsheet. Controls are indicated by arrows.

* 1. Results and Discussion

Figure 2 illustrates the production rates when operating under the eNMPC strategy, as well as for optimal steady-state (SS) and offline DO operations. As expected, with the aid of the buffer tank, the production rate exhibits an inverse relationship with the electricity price profile. Notably, the eNMPC results closely align with the outcomes of the offline DO approach, enabling a heightened degree of operational flexibility when contrasted with the benchmark SS operation. In terms of energy cost savings, both eNMPC and offline DO operations demonstrate substantial benefits, achieving a 28% reduction in costs. Furthermore, the CPU times for solving the DO problems within the eNMPC framework consistently remain below its sampling time, with an average value of 130 seconds, underscoring the real-time feasibility of the eNMPC approach.

* 1. Conclusion

We demonstrate that eNMPC improves the flexible operation of an RSR process while being real-time tractable. The considered RSR process is a biodiesel production subprocess, wherein buffer tanks decouple different process parts, enabling distributed optimization. Consequently, distributed eNMPC emerges as a promising approach for the optimal flexible operation of the entire biodiesel production process.

References

Amrit R., Rawlings J.B., Biegler L.T. (2013). Optimizing process economics online using model predictive control. Comput. Chem. Eng., 58, 334-343.

Caspari A., Bremen A. M., Faust J., Jung F., Kappatou C. D., Sass S., Vaupel Y., Hannemann-Tamás R., Mhamdi A., Mitsos A. (2019). DyOS - A Framework for Optimization of Large-Scale Differential Algebraic Equation Systems. Computer Aided Chemical Engineering: 29 European Symposium on Computer Aided Process Engineering, Kiss A. A., Zondervan E., Lakerveld R., Özkan L., Eds., 46, 619–624.

El Wajeh M., Mhamdi A., Mitsos A. (2023). Optimal design and flexible operation of a fully electrified biodiesel production process. URL <https://arxiv.org/pdf/2308.09537>.