

397f Reducing on-Line Computational Requirement for Real-Time Dynamic Optimization of a Nonlinear Integrated Plant

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An integrated plant with large material and energy recycle loops is known to exhibit a multiple time-scale phenomena, in which the fast dynamics arise from the change in the unit operations and the slow dynamics are induced by interactions from the recycle streams. When the recycle-to-feed ratio is very large, the system becomes extremely ill-conditioned and the settling time of the entire plant will be much longer than the residence time of each unit operation. If the conventional centralized nonlinear model predictive control scheme is used for control and economic optimization, a small sampling time and very large prediction horizon will be required to satisfy both the control and plant-wide economic objective, resulting in unwieldy computational requirement, which is often unachievable in real-time application. In addition, if the control and optimization objectives are included in the same optimizer, the economic performance can be severely compromised for the plant with many real-time disturbances [1]. Based on this consideration, this work adopts a two-layer optimization scheme, in which the plant-wide economic real-time optimizer (RTO) functions on top of the control layer and calculates the optimal setpoints for the controllers in the plant. Previous work [2] suggested that an RTO based on the slow-scale reduced order dynamic model of a linear plant and a slower sampling time (hours⁻¹) outperforms the conventional steady-state RTO and other coincidence point dynamic RTO method. The remaining challenge is how to effectively formulate and solve the nonlinear dynamic real-time optimization of the plant-wide economics at a chosen time scale.

This work provides an insight into methods to overcome the real-time computational issue of the nonlinear dynamic RTO. Methods successfully applied include (1) nonlinear model reduction via proper orthogonal decomposition and (2) use of 'cost-to-go' function obtained via an approximate dynamic programming approach [3]. In the former case, proper orthogonal decomposition technique (combined with data filtering) can be used to identify dominant slow-scale dynamical modes of the multi-scale plant, and the system model is projected onto its empirical eigenfunction subspace arranged from the most to least significant as indicated by the corresponding eigenvalues. A wealth body of research in this area often suggested reducing the projected differential states by truncating the less significant ones, of which eigenvalues are small. However, this work shows that the truncation of a large number of states can lead to poor performance including steady-state offsets. Alternatively, the residualization approach, which assumes the less important states (fast states in this case) are at quasi-steady states gives much better results for the optimization. Nevertheless, the recycle loops can play important role in number of differential states need to be kept. In this presentation, we compare the results of model reduction via truncation and residualization and discuss the case that the benefit of the computational load reduction in the residualization approach may decline when large recycle loop is present.

Another way to dramatically reduce the on-line computational load is to employ the approximate dynamic programming approach, which formulates and solves the multi-stage dynamic optimization problem off-line to yield so called 'cost-to-go' function. The 'cost-to-go' function so obtained can be used to reduce a multi-stage problem into an equivalent single-stage problem, and therefore dramatically lower the on-line computational requirement. However, conventional dynamic programming finds the cost-to-go for every possible state through discretization of entire state space, leading to an exponential growth of computation with respect to the state dimension. To overcome the excessive computation and storage issues of dynamic programming, Lee [3] has introduced the approximate dynamic programming framework to solve the small size optimal control problems. In this work, we discuss the application of such approach to a large-scale plant-wide economic optimization problem. Outstanding issues including the problem formulation and the handling of a much larger state dimension will be discussed. Finally,

the tradeoffs and potential synergy between the reduced-order model-based RTO and the potential approximate dynamic programming RTO will be summarized.

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[2] Tosukhowong, T, Lee, J. M., Lee, J. H., and Lu, J., "An introduction to a dynamic plant-wide optimization strategy for an integrated plant," *Computers and Chemical Engineering*, vol. 29, pp. 199-208, 2004.

[3] Lee, J. M., "A study on architecture, algorithms, and applications of approximate dynamic programming based approach to optimal control," Ph.D. Thesis, Georgia Institute of Technology, 2004.