222c Integrated Process Networks: Nonlinear Control System Design for Optimality and Dynamic Performance

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Grassroots plant designs, as well as the retro-fit design of existing facilities, have in the past decades relied more and more heavily on integration through material and energy recycle streams in order to lower capital costs and increase energy efficiency. Economic improvements come, however, at the cost of an increased dynamic complexity: process networks featuring material and energy recycle streams have been shown to exhibit an intricate nonlinear behavior, oftentimes featuring limit cycles and instabilities. In the current economic environment, featuring frequent market changes and growing natural resource costs, it is advantageous that plants be run at economically optimal operating points, and that the transitions between these operating points be carried out smoothly and efficiently, requirements that call for the design of appropriate control strategies at the network level. Most of the current work in this direction relies, however, on using simple linear controllers within a multi-loop framework, as the design of advanced, model-based controllers for process networks is typically hindered by the size, complexity and -very frequently- by the stiffness of the network dynamic models.

In previous work (Kumar and Daoutidis, JPC, 2002, Baldea, Daoutidis and Kumar, AIChE J., 2006) we have investigated the dynamics of integrated process networks featuring large recycle streams, and, respectively, small purge streams. We have demonstrated that the networks considered exhibit a multiple time scale behavior, featuring an overall, network dynamics that evolves over a slow time scale, and, using singular perturbations arguments, we have derived reduced-order nonlinear models for the dynamics in each time scale. Also, we have proposed a multi-tiered manipulated input selection and model-based controller design framework that naturally accounts for the aforementioned time scale multiplicity. Also, we analyzed the link between the open and closed-loop dynamics of integrated process networks (Araujo, Baldea, Skogestad and Daoutidis, ESCAPE -16, 2006).

In the present work, we address the design of optimal controllers for integrated process networks. Rather than relying on (a computationally expensive) on-line optimization (e.g., MPC, RTO), we propose a two-step approach that merges self-optimizing controller design (Skogestad, JPC, 2000) and the nonlinear dynamic analysis, model reduction and input selection framework proposed in Baldea and Daoutidis, Comp. Chem. Eng. 2006. Self - optimizing (SO) controller design is very appealing from a practical perspective, since it relies on the use of an off-line, steady-state optimization procedure for selecting the controlled outputs of a plant. In the present work, we rely on SO design to identify the controlled outputs (and candidate manipulated inputs) that minimize a pre-defined loss function in the presence of disturbances and changes in plant operating conditions. Subsequently, the analysis framework proposed in Baldea and Daoutidis, Comp. Chem. Eng., 2006 is used to provide a rational pairing between the manipulated inputs available in each time scale and the controlled outputs that have been identified to lead to economic optimality. We then proceed with the derivation of well conditioned nonlinear controllers for tracking and disturbance rejection.

An illustrative example is provided, and comparative simulation runs demonstrate the benefits of the proposed combined approach in terms of economic optimality and dynamic performance, over controller designs carried out using typical design heuristics.

References

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