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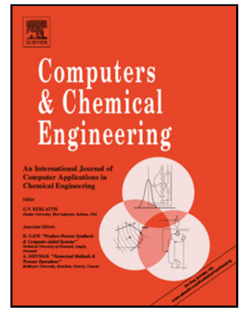

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Decomposing complex plants for distributed control: perspectives from network theory

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Abstract

This paper reviews recent research on the application of methods from the theory of networks for developing distributed control architectures for complex plants. The problem is defined as one of decomposing process networks into constituent subnetworks with strong intra-subnetwork and weak inter-subnetwork interactions. These interactions are quantified based on connectivity and response sensitivity information. This perspective is inspired by the community detection problem in networks. Several approaches are discussed based on hierarchical clustering and modularity optimization. The concepts and potential of these methods for developing control architectures for complex plants are illustrated through a case study. Future research directions are also discussed.

Keywords: Control architecture, network decomposition, community detection, distributed control

1. Introduction

Complex, large-scale plants are prevalent in the process industries. Complexity derives from the underlying physico-chemical phenomena in the individual unit operations as well as from the feedback interconnections (through process integration) among the process units themselves. The former feature has been a major driver for the development of nonlinear predictive control strategies in the last three decades. The latter one has received comparatively less attention.

Yet, large-scale plants with strong interconnections, are very common outcomes of sustainable design practices. Phenomena like disturbance propagation, multi-time-scale dynamics, and emerging, network-level behavior are typically present in such systems (Baldea and Daoutidis, 2012). Further, the need for considering expanded boundaries within a sustainability framework can lead to "system-of-systems" architectures, i.e. physically coupled large scale systems with different functionalities and operational independence, but also linked and therefore interacting through a common management entity (Jamshidi, 2009; Samad and Parisini, 2011). Examples include clusters of industrial processes linked through streams or dynamic supply chain decisions, processing plants competing for multiple utilities/resources, engineering systems coupled with natural systems, cyber-physical systems etc. (Daoutidis et al., 2016). Features such as network-level or multi-time-scale dynamics are present in these systems as well. Finally, we are faced with a global, dynamic enterprise environment, with frequent changes in market conditions and economic objectives. These in turn dictate frequent transitions between different operating points or production protocols, or even changing process designs due to the scheduling and planning decisions. All these arguments point to the need to go beyond a "static" regulatory plant-wide control system, to a responsive and flexible one, that can accommodate frequent transitions over a wide operating window, and even reconfigurations of the control architecture itself.

Most plant-wide control approaches adopt a decentralized control paradigm, which can be limited in its effectiveness when process integration is tight. This is one of the reasons that practical implementations of highly integrated designs are approached cautiously by process control engineers. Operability and control of such integrated designs is a challenge which must be addressed in order to realize the benefits of integration. The best way to achieve this goal can and should be debated. Developing further the computational efficiency of model predictive control formulations and implementations is one possible direction (see e.g. Biegler and Zavala (2009); Patterson and Rao (2014); Biegler (2017)). A lot of recent research activity has also focused on analyzing properties of process networks such as passivity or dissipativity that facilitate stabilization and control (Jillson and Ydstie, 2007; Hudon and Bao, 2012). Another direction, for plants with large inventory recycle flows, exploits the emergence of slow plant-level dynamics through a hierarchical control structure (Baldea and Daoutidis, 2012, 2014; Jogwar et al., 2015) with process and plant level control objectives addressed in different time scales using different sets of ma-

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