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Plantwide operability assessment for nonlinear processes using a microscopic level network analysis

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ABSTRACT

The increase of raw material and energy costs has caused a shift in process design philosophy leading to more complex chemical plants utilising heat integration and material recycles. This warrants plantwide dynamic operability analysis in the process design stage. In our previous work, a networked plantwide operability analysis approach was developed, where the plantwide process is viewed as a network of process units connected via mass and energy flow. Such an analysis is based on the dissipativity of each process unit and the topology of the process network. However, to determine the dissipativity of multivariable nonlinear process units is often extremely difficult. In this work, we take the network approach to a microscopic level and treat each nonlinear multivariable process unit as a network of individual (single state) mass and energy balances (sub-systems). The plantwide process is then viewed as a network of such sub-systems rather than physical process units. The dissipativity of these simple sub-systems can often be determined more easily in comparison to that of multivariable sub-systems. The dissipativity property (in terms of supply rate) of the entire nonlinear process can be parametrised by the dissipativity of individual sub-systems, leading to a cluster of supply rates. The operability of the plantwide nonlinear process can then be determined based on the above parametrised dissipativity which can be much less conservative than existing nonlinear analysis. The effects of interactions caused by the interconnections are considered explicitly based on the network topology. The stability and stabilisability analysis problem is then converted into a feasibility problem with linear matrix inequalities which can be solved numerically. The application of the proposed approach requires successful determination of the dissipativity of nonlinear sub-systems.

Keywords: Plantwide operability analysis; Stability; Stabilisability; Dissipativity; Nonlinear systems; Network perspective

1. Introduction

Incorporating the process dynamics in process design has become a more common practice in the industry. Processes that were designed based only on steady-state economic considerations often suffer from the difficulty during operation (Luyben et al., 1998). With the increasing complexity of modern chemical processes due to the extensive use of recycle streams and heat integration, it becomes more important to study how the process design imposes limitation on the dynamic control performance, which is called dynamic operability analysis. Operational difficulties identified after commissioning the plant may result in re-design and re-build which often lead to significant financial penalty. Many of these difficulties are caused by the inherent nonlinear dynamics of chemical processes and the interactions between the basic process mechanisms (Hernjak et al., 2004).

Dynamic process operability study typically includes the analysis on plantwide stability, stabilisability, and achievable control performance. This paper is focused on the first two elements but can be extended to address other aspects. In control theory, a nonlinear system is said to be input–output stable if its output is bounded for any given bounded input. Stability of a chemical process is an important desirable property as it ensures that the process output will not run away under any operating conditions and is therefore directly linked to process safety and economy. For a plant that is unstable (e.g., an exothermic reactor which is non-self regulating), then it

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