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Control and optimization strategies for thermo-mechanical pulping processes: Nonlinear model predictive control

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ABSTRACT

In this paper, we present nonlinear model predictive control (NMPC) techniques to control and optimize the thermo-mechanical pulping (TMP) process. The TMP process considered in this work has two-stages of refining with a primary and a secondary refiners. TMP processes are, inherently, multi-input multi-output (MIMO) processes with complex dynamics and severe interactions among process variables. We formulate a dynamic optimization problem to simultaneously regulate and optimize the TMP process and compare with regulatory control in the presence of disturbances. Potential economical benefits of the proposed method are demonstrated, through a reduction in total specific energy. The computational burden of the resulting nonlinear programming problem (NLP) is handled with the IPOPT (Interior Point OPTimizer) solver. This is further improved with the *advanced step* NMPC (asNMPC) controller concept, a sensitivity-based approximation to the solution of the resulting NLP problem in NMPC.

1. Introduction

Although the thermo-mechanical pulping (TMP) process is a mainstay of the pulping industry, TMP mills face a number of challenges due to increasing electricity costs, and a drive to reduce green house gas emissions. TMP mills need to reduce electrical energy consumption, thereby reducing production cost and environmental impact [1,2]. In addition, pulp mills have to produce improved pulp with less variability in pulp quality in order to face competitors and retain customers [3]. At present, TMP mills are seeking advanced process control techniques to minimize energy consumption and improve pulp quality in order to address the above challenges. Chips refiners are the most energy-vore units in the TMP process, and there is considerable literature on implementation of advanced control systems for them [3–5]. However, it has been reported that advanced control systems have failed to perform well over for long period: over 90% of all advanced control applications have been turned off within a year [3]. Major reasons for poor performance of advanced control systems are (i) the lesser attention being paid to low-level regulatory control and (ii) the linearity assumption of the TMP process. In addition, operator training and servicing after installation need to be improved for reliable and continuing operation of advanced control systems.

Nonlinear model predictive control (NMPC) has been applied to control and optimize chemical processes [6,7]. MPC is an advanced control technique, which calculates future control actions at each sample time, by solving a finite horizon optimization control problem. One of the main advantages of MPC is its ability to cope with hard constraints on control and state variables. Therefore, MPC has attracted considerable research effort, and has been widely applied in process industries for low-level regulatory control under constraints [8,9]. With the improvement of today's computational power and development of efficient nonlinear programming (NLP) solvers [10] and tailored algorithms [11], there is growing tendency to use NMPC in the optimization layer of the decision making hierarchy, using detailed nonlinear dynamic models.

Computer control of wood-chip refiners has been studied in the literature and industry for a long time [12], and there have been a few attempts to control and optimize TMP processes using MPC strategy. Ruscio [13,14] demonstrated a linear MPC control technique for a TMP process. The objective of that work was to control specific energy and consistency of the TMP process using screw speed, dilution flow and plate gap. First, a subspace identification technique was presented, and then a linear state-space model was identified with time series data to use for MPC. Du et al. [15] presented a generalized predictive control (GPC) algorithm based on a nonlinear Laguerre model to control motor load and consistency of a TMP process. They demonstrated that pad collapse can also be avoided with the use of nonlinear Laguerre model. In addition, there are a few applications reported to control pulp quality and reject refining process using MPC [1,16]. Recently, Sidhu et al. [5]

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