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A strategy for the integration of production planning and reactive scheduling in the optimization of a hydrogen supply network

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Abstract

In this paper, we address the integration of production planning and reactive scheduling for the optimization of a hydrogen supply network consisting of five plants, four inter-connected pipelines and 20 customers. We present multiperiod mixed integer nonlinear programming (MINLP) models for both the planning and scheduling levels. The planning model includes complex pricing functions resulting from deregulation, with a simplified pipeline description and determines feed and energy prices, as well as production levels, for a monthly horizon divided into 12-h time periods. Prices are fixed on the scheduling level, while a detailed pipeline model is included, to determine the on/off status and load steps of compressors on an hourly basis, in order to satisfy the actual demands as they become known while adhering to pressure constraints. In addition, we propose a solution methodology where the demand forecast is updated and the planning model is rerun every 12 h, while the scheduling model is run every hour and information is passed between the two levels to facilitate integration. We show that the planning model quickly becomes intractable and propose a heuristic solution method for this level based on Lagrangean decomposition. Results show that the proposed Lagrangean decomposition heuristic reduces the computational effort for solving the planning model by more than an order of magnitude compared to the commercial MINLP solver DICOPT++. It is also shown that for the majority of the plants, the power consumption and hydrogen production from the scheduling level agrees with the planning level. In some cases, however, the integration is hampered by the presence of nonlinearities, especially on the scheduling level, that lead to suboptimal or infeasible solutions. These nonlinearities need to be further addressed before the proposed methodology can be implemented in practice.

Keywords: Planning; Scheduling; Pipeline; Optimization

1. Introduction

The integration of planning and scheduling in optimization has received increasing attention in recent years (e.g. Birewar & Grossmann, 1990; Coxhead, 1994; Papageorgiou & Pantelides, 1996a; Papageorgiou and Pantelides, 1996b; Petkov & Maranas, 1997; Sand, Engell, Märkert, Schultz & Schulz, 2000; Rodrigues, Latre & Rodrigues, 2000; Lasschuit and Thijssen, 2003; Neiro and Pinto, 2003). This trend follows the realization in industry that planning and scheduling decisions need to be considered simultaneously to gain a competitive advantage (see e.g. Shobrys and White, 2000). Two of the major challenges towards this integration are dealing with the different time scales and with the problem size of the resulting optimization model. In this work, we address these challenges by considering the integration of production planning and reactive scheduling in the optimization of a hydrogen supply network. An additional challenge that arises is the modeling and solution of the pipeline system. Pipeline flow models are difficult to solve due to the presence of nonlinear functions such as absolute values, signs (+ or −), and flow transitions that result in discontinuities and other non-convexities. It is, however, important to include these details in the model to ensure feasible flows and to satisfy customer demands and minimum contract pressure levels.

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Nomenclature

Sets:

J	plants
OG(J)	offgas plants
OD(J)	on-demand plants
K	compressors
iden_$k(K,K')$	compressors K and K' are identical
A	compressor load steps
L	pipelines
H2$L(L)$	hydrogen pipelines
OG$L(L)$	offgas pipelines
TG$L(L)$	tailgas pipelines
k_config(K,J,L)	configuration of compressor K associated with plant J and pipeline L
$c^2\ (K,J,L)$	compressors with control structure 2
C	customers
T	time periods
$T^{\text{on}}\ (T)$	on-peak time periods
$T^{\text{off}}\ (T)$	off-peak time periods
N^{peak}	number of peaks to be used in energy price calculation
N	pipeline nodes
N_pipe$(H2L,N)$	node N associated with pipeline $H2L$
P_node(J,N)	plant P flowing into node N
C_node(C,N)	customer C flowing out of node N
arc(n,n')	arc between node n and n'
PCV(N,N')	arc N to N' is a pressure control valve

Indices:

j	plants $j \in J$
k	compressor $k \in K$
a	load step $a \in A$
l	pipeline $l \in L$
c	customer $c \in C$
t	time period $t \in T$
n^{peak}	peak period $n^{\text{peak}} \in N^{\text{peak}}$
n	node $n \in N$

Parameters:

$a^{\text{turb}}_{n,n'}$	coefficient for calculating turbulent Reynolds number
a_{0j}, a_{1j}, a_{2j}, a_{3j}	coefficients for calculating natural gas flow for on demand plant j
a_j^{NGM}	first coefficient for calculating NGM$_j$
annon$_j$	on peak average power usage for the past 12 months for plant j
aux$_j^1$, aux$_j^2$, aux$_j^3$	coefficients for calculating auxiliary power used by plant j
$b^{\text{turb}}_{n,n'}$	coefficient for calculating turbulent Reynolds number
b_{0j}, b_{1j}, b_{2j}	coefficients for calculating steam flow for on demand plant j
b_j^{NGM}	second coefficient for calculating NGM$_j$
$c^{\text{turb}}_{n,n'}$	coefficient for calculating turbulent Reynolds number
c^{dPdz}	conversion factor for driving force calculation
$c^{\text{powercost}}$	factor for power cost calculation
c_j^{base}	base cost coefficient for power cost calculation for plant j
c_j^{NGPrice}	constant including natural gas price for offgas plant j
c_j^{prim}	primary cost coefficient for power cost calculation for plant j
c_j^{recov}	constant used for H_2 recovery calculation for offgas plant j
c_j^{scnd}	secondary cost coefficient for power cost calculation for plant j
c_j^{steam}	correction factor for steam calculation for on demand plant j
custdem$_{c,l,t}$	demand from customer c on pipeline l in period t