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A rolling horizon stochastic programming approach for the integrated planning of production and utility systems

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ABSTRACT

This study focuses on the operational and resource-constrained condition-based cleaning planning problem of integrated production and utility systems under uncertainty. For the problem under consideration, a two-stage scenario-based stochastic programming model that follows a rolling horizon modeling representation is introduced; resulting in a hybrid reactive-proactive planning approach. In the stochastic programming model, all the binary variables related to the operational status (i.e., startup, operating, shutdown, under online or offline cleaning) of the production and utility units are considered as first-stage variables (i.e., scenario independent), and most of the remaining continuous variables are second-stage variables (i.e., scenario dependent). In addition, enhanced unit performance degradation and recovery models due to the cumulative operating level deviation and cumulative operating times are presented. Terminal constraints for minimum inventory levels for utilities and products as well as maximum unit performance degradation levels are also introduced. Two case studies are presented to highlight the applicability and the particular features of the proposed approach as an effective means of dealing with the sophisticated integrated planning problem considered in highly dynamic environments.

1. Introduction

The process industry is a key economic sector globally. The global market share and business performance of the process industry is heavily based on the value that can be generated from its assets and while the range of valuable assets is large, nearly all the economic value in terms of operating profit in the process industry is a direct result of operations of plant equipment (Christofides et al., 2007). Also, major plant equipment constitute highly expensive capital assets that are typically subject to performance degradation and require periodic maintenance to avoid their damage or inefficient operation. Typically, maintenance planning follows very conservative approaches and is done separately from the production planning. Such approaches result in increased needs for maintenance resources (and associated costs), material waste, and productivity losses. All these, make clear the imperative need for systematic approaches for the efficient management of equipment operations and maintenance to preserve the major assets of a process industry and increase financial gains and competitiveness.

In process industries, a sequential approach is typically used for the operational planning of utility and production systems. First, the planning of the production system is performed considering simply upper bounds on the availability of utilities. Once the production plan is derived, the utility needs of the production are known. This information is then used to obtain the operational planning of the utility system. This sequential approach provides suboptimal solutions (mainly in terms of resource and energy efficiency and costs) because the two interconnected systems are not optimized at the same time. Importantly, the sequential approach often faces the risk of providing utilities generation targets that cannot be met by the energy system (i.e., infeasible solutions), and in that case a re-planning of the production system is usually employed (Zulkafli and

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Nomenclature

Indices/sets

$e \in E$	Resources (products and utilities)
$i \in I$	Units (production and utility)
$n \in N$	Scenarios
$q \in Q$	Offline cleaning task options
$t \in T$	Time periodss
$z \in Z$	Inventory tanks for resources

Superscripts

es	Earliest
fix	Fixed
ls	Latest
max	Maximum
min	Minimum
off	Offline
on	Online
PR	Production system
UT	Utility system
var	Variable
+	Inlet
−	Outlet

Subsets

CB_i	Units *i* that are subject to condition-based cleaning tasks
DM_i	Units *i* that are under in-progress offline cleaning at the beginning of the planning horizon (information carried over from previous planning horizon)
E_i	Resources that can be produced in unit *i*
E^{PR}	Product resources
E^{UT}	Utility resources
FM_i	Units *i* that are subject to flexible time-window offline cleaning
I_e	Units that can produced resource *e*
I^{SF}	Units that are subject to startup and shutdown costs
$I^{S-\min}$	Units that are subject to minimum runtimes
$I^{F-\min}$	units that are subject to minimum shutdown times
I_e^{PR}	Production units that require utility *e* to operate
MR_i	Units *i* that are subject to maximum runtime constraints
PR_i	Production units
Q_i	Alternative offline cleaning task options for unit *i*
UT_i	Utility units
Z_e	Inventory tanks that can store resource *e*
Z_i	Units *i* connected to the input/output of inventory tank z

Parameters

$\alpha_{(i,e,e')}$	Coefficient for production unit *i* that provides the variable needs for utility e for the production of a unit of product e'
$\overline{\alpha}_{(i,e,e')}$	Coefficient for production unit *i* that provides the fixed needs for utilities *e* for the production of product e'
β_z^{loss}	Coefficient of losses in inventory tank
γ_i^{on}	Minimum time between two consecutive online cleanings in unit *i*
δ_i	Performance degradation rate for unit *i* due to its cumulative time of operation
δ_i^q	Performance coefficient related to operating level for unit *i* due to its cumulative deviation from its reference operating level
δ_n^p	Probability of occurrence for each scenario *n*
$\varepsilon_{(e,z,t)}$	Bounds on the total inlet/outlet flow of resource *e* to/from inventory tank *z* in time period *t*
$\zeta_{(e,t)}$	Demand for product *e* in time period *t*
$\eta_t^{\max}$	Limited amount of available resources for cleaning operations in time period *t*
$\vartheta_{(i,q)}^{off}$	Resource requirements for offline cleaning task option *q* of unit *i*
ϑ_i^{on}	Resource requirements for online cleaning of unit *i*
$\kappa_{(i,t)}$	Bounds on the operating level for utility unit $i \in UT_i$ in time period *t*
$\overline{\kappa}_{(i,e,t)}$	Bounds on the production level of product *e* for production unit $i \in PR_i$ in time period *t*