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Resource–Task Network Formulations for Industrial Demand Side Management of a Steel Plant

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ABSTRACT: In today's energy markets, there is a growing effort toward the alignment of the industrial sector and the power grid for the sake of efficient energy distribution and consumption. In this paper, the resource–task network is used to provide a generic modeling framework for production scheduling under energy constraints. Three alternative process models for the energy-intensive melt shop of a steel plant are proposed and linked to a discrete-time formulation. The results show a trade-off between accurate representation of problem data and computational performance. By keeping track of the total energy and power consumption through time, we study the impact of fluctuating energy prices on the scheduling of operations and the economic benefits that can be obtained from the plant's participation in the price- and incentive-based industrial demand side management programs.

1. INTRODUCTION

In the coming decades, the energy sector in Europe will face a fundamental shift toward renewable electricity generation, mostly from wind power. Wind supply is generally unresponsive to need and is associated with a high level of uncertainty due to the volatile nature of wind. It will have price effects on the spot market and will lead to a growing demand for positive and negative balancing power.[1] One way to provide the required stability and flexibility to the power system is through demand side management (DSM), which can be categorized as either reducing energy consumption or rescheduling and shifting energy demand to off-peak hours. Large-scale, energy intensive processes may play an important role in this context, and the question that arises in the scientific community is how to balance electricity supply and availability against the underlying profitable conditions for industry.

In the industrial demand side management (iDSM) or demand response (DR) grid-consumer interface, the electricity provider gives economic incentives to the industry to alter their electricity usage behavior and there are generally two approaches:

- Price-based program. Customers respond to the electricity price structure (e.g., day-ahead market) with voluntary changes in their timing of electricity usage, taking advantage of low-priced periods and avoiding production in high-priced periods.
- Incentive-based program. Customers can obtain electricity at a reduced cost, if the electricity consumption is contracted ahead of time (e.g., a few days to weeks in advance). The consumption curve then has to be followed as closely as possible to avoid penalties for over- and underconsumption of electricity.

A recent study investigating the potential of iDSM for electricity markets in Germany[1] identified that electric arc furnaces in steel manufacturing can provide a significant positive reserve capacity by decreasing demand when the electricity system falls short on capacity. However, they also recognize that possible disruptions in the process resulting from participation in the spot market may compromise meeting contracted loads in the future, thus reducing the probability for actual calls for energy, to close to zero.

Steel manufacturing is recognized as one of the most difficult industrial processes to schedule[2] (a large-scale, multistage, and multiproduct batch process involving parallel equipment, nested decisions, and critical production and energy-related constraints). Because of this, steel plant scheduling solutions or teams have traditionally focused on minimizing the makespan or changeover costs or deriving solely a feasible schedule. In order to minimize the energy cost and ensure profitability, the optimization of production planning and scheduling under energy constraints forms an important tool for the steel industry to leverage.

Nolde and Morari[3] proposed a continuous-time scheduling formulation for electricity load tracking of a steel plant with an identical layout to the one in the work of Harjunkoski and Grossmann.[2] The problem consists of scheduling the production tasks such that the energy consumption is kept as close as possible to a prespecified energy curve to avoid penalties from the electricity provider. Power consumption of tasks is given as parameters, but their processing times are allowed to vary between minimum and maximum values to provide scheduling flexibility. Results for the production of 15 identical batches of steel over a day showed that with load tracking scheduling, the plant owner can potentially reduce his energy costs significantly. An improved continuous-time mixed-integer linear programming (MILP) for the same problem has

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