Energy-SmartOps Integrated Control and Operation of Process, Rotating Machinery and Electrical Equipment

Electricity Demand Side Management in Steel Plant Scheduling

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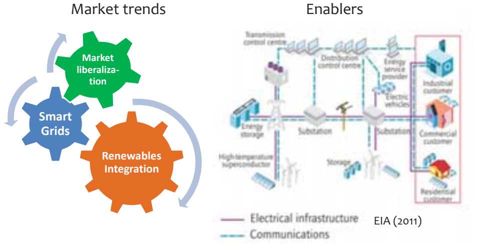
Motivation and background



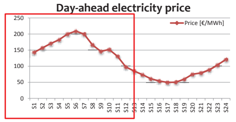
Process industry can help by actively managing their load – **Electricity Demand Side Management**

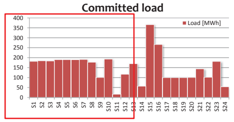
Grid & Process balancing

Goal and problem statement

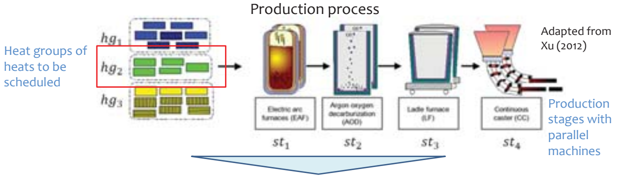
Given

- Set of heats $p \in P$
- Ordered in heat groups $hg \in HG$
- Set of production stages $st \in ST$
- Set of machines $m \in M$
- Set of price intervals $s \in S$
- Electricity prices $e_s \in E$
- Committed load $a_s \in A$





Production process



Optimized production schedule

Research methodology and solution approach

Mixed Integer Linear Programming monolithic model (Hadera & Harjunkoski 2013) implemented in GAMS/CPLEX

- Continuous-time melt shop scheduling with precedence and assignment variables (Harjunkoski & Grossmann 2001, Harjunkoski & Sand 2008)

$$t^s_{p,st+1} = t^f_{p,st} + w_{p,st} \qquad \forall p \in P,\ m \in M,\ st \in ST,\ \{st,m\} \in SM_{st,m},\ st < |ST| \quad (1a)$$

Subsequent stage starts after previous and waiting time

$$w_{p,st} \geq t^{min}_{m,m'}(X_{m,p} + X_{m',p} - 1) \qquad \forall p \in P, st \in ST, m, m' \in M, \{st,m\} \in SM_{st,m}, \{st+1,m'\} \in SM_{st,m}, m \neq m', st \neq |ST| \quad (1b)$$

Minimum transportation time

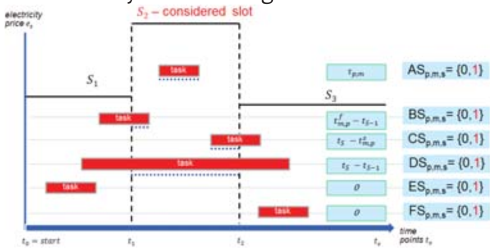
$$w_{p,st} \leq t^{max}_{p,st} \qquad \forall p \in P,\ st \in ST \quad (1c)$$

Maximum holdup time

$$t^s_{m,p'} \geq t^f_{m,p} + t^{setup}_m - M(3 - Y_{st,p,p'} - X_{m,p} - X_{m,p'}) \qquad \forall p,p' \in P, m \in M, st \in ST, \{st,m\} \in SM_{st,m}, p \neq p', st < |ST| \quad (1d)$$

Subsequent heat starts after previous finishes and setup is carried out (CC requires more constraints)

- Electricity-aware time grid with task-time slot relations (Nolde & Morari 2010)



Example: for time slot S_2 slot case $AS_{p,m,s}$:

$$t^f_{m,p} \leq t_s + M(1 - AS_{p,m,s}) \quad (2a)$$

$$t^s_{m,p} \geq t_{s-1} - M(1 - AS_{p,m,s}) \quad (2b)$$

$\forall m \in M, p \in P, s \in S$

If finish and start times of a task are between slot boundaries then binary $AS_{p,m,s}$ is true

- Volatile electricity price response

$$q_s = \sum_{p,m} h_{p,m}(AS_{p,m,s}\tau_{p,m} + bs_{p,m,s} + cs_{p,m,s} + DS_{p,m,s}(t_s - t_{s-1}))\frac{1}{60} \qquad \forall m \in M, p \in P, s \in S \quad (3a)$$

q_s is the electricity consumption of a given slot

$$\mu = \sum_s e_s \cdot q_s \qquad \forall s \in S \quad (3b)$$

Electricity cost

- Load deviation response

$$b_s \leq a_s \cdot b^{over}_s \qquad \forall s \in S \quad (4a)$$

$$b_s \geq -a_s \cdot b^{uder}_s \qquad \forall s \in S \quad (4b)$$

$$d_s = a_s + c^{over}_s - c^{under}_s + b_s \qquad \forall s \in S \quad (4c)$$

Penalties from load deviation depend on the fine levels and amount of electricity under or over consumed

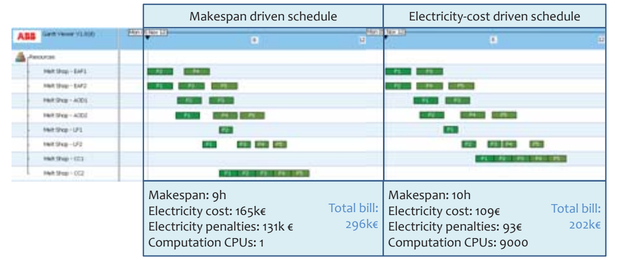
$$\delta = p^{over} \cdot \sum_s c^{over}_s + p^{under} \cdot \sum_s c^{under}_s \qquad \forall s \in S \quad (4d)$$

- Objective function

$$\min \sum_s c \cdot t^{ms} + \mu + \delta \qquad \forall s \in S \quad (5)$$

Minimize the weighted makespan, electricity cost and electricity penalties paid

Results and discussion



Makespan driven schedule	Electricity-cost driven schedule
Makespan: 9h Electricity cost: 165k€ Electricity penalties: 131k € Computation CPUs: 1 Total bill: 296k€	Makespan: 10h Electricity cost: 109€ Electricity penalties: 93€ Computation CPUs: 9000 Total bill: 202k€

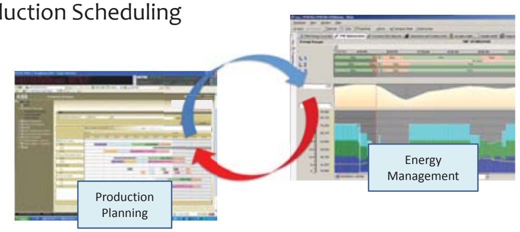
✓ Comparison: 1h schedule delay, 31% savings on electricity cost

X Monolithic model too complex to solve a large scale problem

Further work

- Detailed EAF stage scheduling
- Alternative mathematical formulations
- Integration of Energy Management with Production Scheduling

To enable computing a real-world problem size in reasonable time



References

- EIA - US Energy Information Administration, 2011, International Energy Outlook, Paris
- H. Hadera and I. Harjunkoski, 2013, Continuous-time batch scheduling approach for optimizing electricity consumption, Proceedings of the 23rd ESCAPE, 9-12 June 2013, Lappeenranta, Finland (in preparation)
- I. Harjunkoski and I. E. Grossmann, 2001, A Decomposition Approach for the Scheduling of a Steel Plant Production, Computers & Chemical Engineering, 25, pp. 1647-1660
- I. Harjunkoski and G. Sand, 2008, Flexible and configurable MILP models for meltshop scheduling optimization, Computer Aided Chemical Engineering, Volume 25, Pages 677-682
- K. Nolde and M. Morari, 2010, Electrical load tracking scheduling of a steel plant, Computers & Chemical Engineering, 34, pp. 1899-1903
- Ch. Xu, 2012, Coordination of Large-scale Scheduling Problems with Application to Steel Production (PhD Dissertation submitted)

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