Combinatorial optimization with multiple resources and energy constraints

Optimisation sous contraintes de ressources énergétiques multiples (OREM)

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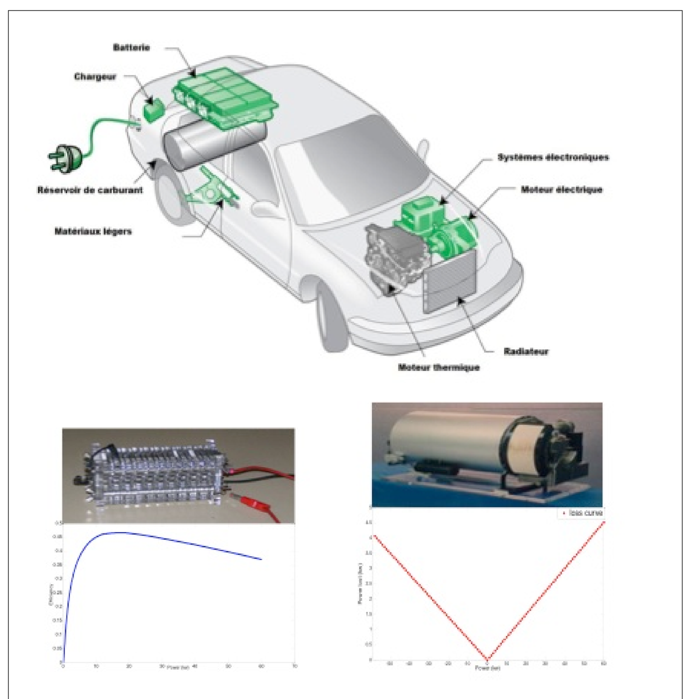
Introduction

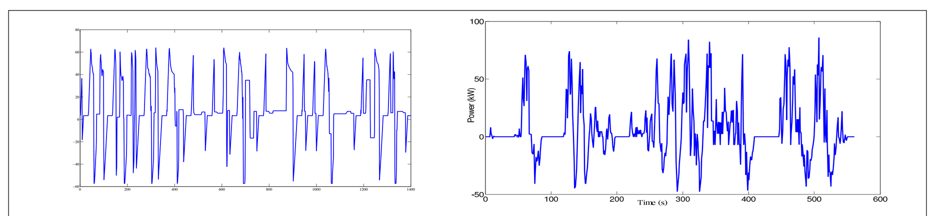
The integration of energy constraints in deterministic scheduling models, such as job-shop scheduling or resource-constrained project scheduling, yields a combinatorial optimization challenge. It follows that the literature on this subject is sparse. In the OREM project, we focus on a scheduling problem where activities must fit into time windows and require an energetic resource. Each activity has an energy demand. The energetic resource has a limited instantaneous availability (maximum available power). As soon as it is started and not completed, the activity must be assigned, at every time point, a power lying within an interval. For each activity, the total energy brought must fulfill its demand. At every time point, the power consumed by all activities cannot reach the resource availability.

Some applications

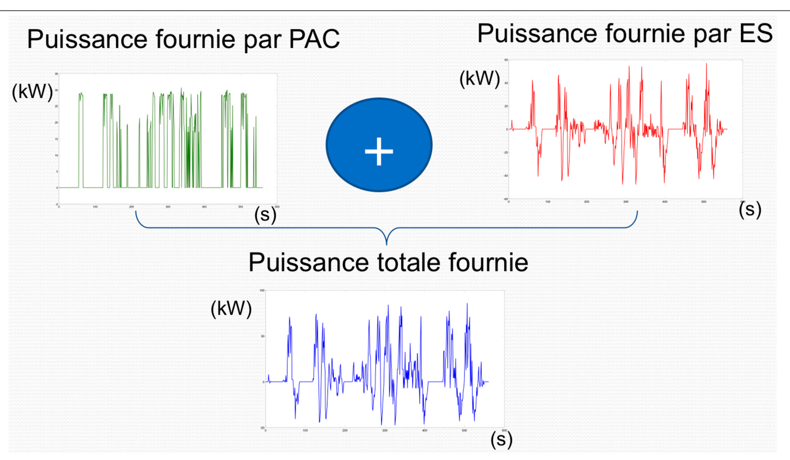
Hybrid-Electric Vehicles



Multiple energy sources available for the vehicle propulsion

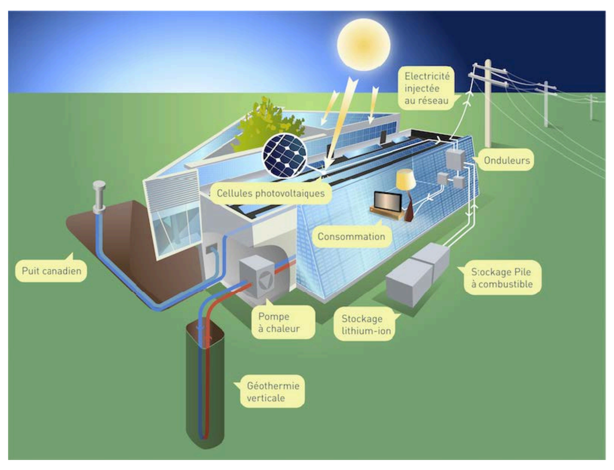


Various power demand profiles



Research the best power split among the sources

Smart grids in smart buildings



The smart building ADREAM of the LAAS

Problem with a single resource

Definition

For each task $i \in A$, find a feasible curve $b_i(t)$, $t \in \mathcal{T}$.

Parameters

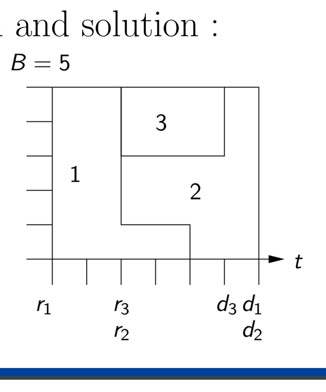
- A resource availability $B \in \mathbb{N}$ to respect
- A set of tasks $A = \{1, 2, \ldots, n\}$.
  - Minimum instantaneous consumption (demand) $b_i^{\min} \in \mathbb{N}$
  - Maximum instantaneous consumption (demand) $b_i^{\max} \in \mathbb{N}$
  - Energy required W_i,
  - Release date $r_i \in \mathbb{N}$,
  - Due date $d_i \in \mathbb{N}$
- Time domain $\mathcal{T}$, Demand domain $\mathcal{B}$

Conceptual model and illustration

$$
\begin{aligned}
r_i \le st_i \le ft_i \le d_i & \quad (i \in A)\\
b_i^{\min} \le b_i(t) \le b_i^{\max} & \quad (i \in A\,; t \in [st_i, ft_i])\\
b_i(t) = 0 & \quad (i \in A\,; t \in \mathcal{T} \setminus [st_i, ft_i])\\
\int_{st_i}^{ft_i} b_i(t)dt = W_i & \quad (i \in A)\\
\sum_{i \in A} b_i(t) \le B & \quad (t \in \mathcal{T})
\end{aligned}
$$

Example of problem and solution :

i	r_i	d_i	W_i	$b_i^{\min}$	$b_i^{\max}$
1	0	6	12	1	5
2	2	6	12	2	5
3	2	5	6	2	2



Mathematical formulation for the single-resource case

Variables

- Demand curves $b_i(t) : \mathcal{T} \to \mathcal{B}$, $i \in A$
- Indicator of task started x_{it}
- Indicator of task ended y_{it}

4 variants

- Continuous time horizon $\mathcal{T} \subseteq \mathbb{R}$ **or** Discrete time horizon $\mathcal{T} \subseteq \mathbb{N}$
- Continuous demands $\mathcal{B} \subseteq \mathbb{R}$ **or** Discrete demands $\mathcal{B} \subseteq \mathbb{N}$

Discrete-time mathematical model ([2])

$$
\begin{aligned}
& \max \left(\sum_{i \in A} \sum_{r_j}^{d_j - 1} b_{it} \right) & \\
& \sum_{t=r_i}^{d_i-1} x_{it} = \sum_{t=r_i+1}^{d_i} y_{it} = 1 & \forall i \in A\\
& \sum_{s=r_i+1}^{t} y_{is} b_i^{min} + b_{it} - \sum_{s=r_i}^{t} x_{is} b_i^{min} \ge 0 & \forall i \in A, \forall t \in [r_i, d_i] \cap T\\
& \sum_{t=r_i}^{d_i-1} b_{it} = W_i & \forall i \in A\\
& \sum_{i \in A} b_{it} \le B & \forall t \in T\\
& \sum_{s=r_i+1}^{t} y_{is} b_i^{max} + b_{it} \le b_i^{max} & \forall t \in \{r_i \ldots d_i - 1\}, \forall i \in A\\
& \sum_{s=r_i+1}^{t} y_{is} - \sum_{s=r_i}^{t} x_{is} \le 0 & \forall t \in \{r_j + 1 \ldots d_j\}, \forall i \in A\\
& \sum_{s=0}^{t} x_{is} w_i - b_{it} \ge 0 & \forall t \in \{r_j + 1 \ldots d_j\}, \forall i \in A\\
& \sum_{s=0}^{r_i-1} x_{is} = \sum_{s=d_i+1}^{T} y_{is} = \sum_{s=0}^{r_i-1} b_{is} = \sum_{s=d_i}^{T} b_{is} = 0 & \forall i \in A\\
& x_{it}, y_{it} \in \{0,1\} \quad b_{it} \ge 0 & \forall i \in A, \forall t \in T
\end{aligned}
$$

Methodology and Contributions expected

Phase 1 : Solving the single-resource case

- Mathematical formulation of the different variants
- Identification of valid inequalities and dedicated separation procedures

Phase 2 : Solving the multi-resource case

- Extension of the mathematical model and the valid inequalities to the multi-resource case
- Definition of patterns of resource consumption and procedure for feasible patterns generation with regard to predefined constraints
- Development of a column-generation-based algorithm to exploit the feasible patterns identified

Phase 3 : Experimental Validation

- Introduction of more realistic consumption/production curves
- Tests on data sets of realistic power profiles for hybrid electric vehicles and mission profiles provided by the researchers in Electrical Engineering from LAPLACE
- Experimentations on the smart building ADREAM of the LAAS (http ://www.laas.fr/ADREAM/)

Expected Contributions

- Integration of energy sources selection in scheduling, taking into account constraints related to the efficiency of technological equipments and their dynamics, both related to the characteristics of each energy source.
- New hybridization of techniques and solution methods : combination of patterns generation (including dual solutions-based filtering) and propagation of resources constraints for the scheduling problem considered.

References

[1] C. Artigues, P. Lopez and A. Haït, The energy scheduling problem : industrial case study and constraint propagation techniques, Int. J. Prod. Econ., 143(1) :13-23, 2013

[2] C. Artigues, P. Lopez, D. Rivreau, Raisonnement énergétique et inégalités valides pour un problème d'ordonnancement sous contraintes d'énergie. ROADEF 2013, Tours, France.

[3] M. Guemri, S. Caux, S.U. Ngueveu, and F. Messine. Heuristics and lower bound for energy management in hybrid-electric vehicles. In Proceedings of 9th International Conference of Modeling, Optimization and Simulation (MOSIM 2012), paper 169, 10 pages, Bordeaux, France, 2012.