Increase in power demand guarantee: a bilevel approach

Mathieu Besançon, Luce Brotcorne, Miguel Anjos, Juan Gomez-Herrera

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Mathieu Besançon
Supervisors: Luce Brotcorne & Miguel F. Anjos
Juan A. Gomez-Herrera

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Polytechnique Montréal - GERAD - INRIA INOCS

Outline

Introduction

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Changing context for power grids:

- Integration of Distributed Renewable Sources
- Easier, automated data exchange
- Contribution of energy users to better grid operations

Multi-objective, bilevel optimization:

- NP-hard problem to solve or prove optimality in the general case [1]
- Choose trade-off upfront or after building front?

Problem context, design goals

Context:

- Generation planning requires information on demand
- More than forecast, **guarantee** on consumption
- Demand Response still not targeting residential users

Design goals:

- Offer users cost reductions for this guarantee on demand
- Maintain privacy and user-side flexibility by design
- Minimal information exchange and user actions

Time-and-Level-of-Use tariff

Time-and-Level-of-Use tariff

Introduced in Gomez-Herrera & Anjos 2017 [2]
A capacity is booked by the user before consumption
Policy described by:

- K, booking fee
- π^L, lower tariff decreasing with capacity
- π^H, higher tariff increasing with capacity

$$\text{User cost} = \text{Booking cost} + \text{Expected energy cost}$$
$$\text{User cost}(c) = K \cdot c + \text{Expected energy cost}$$

TLOU operational steps

1. Supplier sends pricing
2. Consumers book a capacity
3. After consumption, total cost is computed and billed

Done for each time frame, at least day-ahead in the base case considered.

Bilevel formulation

Decision variables

Supplier chooses a price setting:

- $K \geq 0$
- $\pi^L \in \mathbb{R}^{|\pi^L|} \geq 0$
- $\pi^H \in \mathbb{R}^{|\pi^H|} \geq 0$

$\pi^L(0) = \pi^H(0)$: the baseline Time-of-Use price.
User:

- Booked capacity for the time frame $c \geq 0$

User and supplier objectives

User minimizes their total expected cost:

$$\min_c K \cdot c + \sum_{\omega \in \Omega^-(c)} \pi^L(c) \cdot p_\omega \cdot x_\omega + \sum_{\omega \in \Omega^+(c)} \pi^H(c) \cdot p_\omega \cdot x_\omega$$

Supplier minimizes the difference in profit between the baseline and current solution:

$$L^F \equiv \sum_{\omega \in \Omega} p_\omega \cdot x_\omega \cdot \pi_0^H - \left(K \cdot c + \sum_{\omega \in \Omega^-(c)} \pi^L(c) \cdot p_\omega \cdot x_\omega + \sum_{\omega \in \Omega^+(c)} \pi^H(c) \cdot p_\omega \cdot x_\omega \right)$$

L^F: conflicting user and supplier, min-max problem:

$$\min_{K, \pi^L, \pi^H} \max_c \quad L^F(K, \pi^L, \pi^H, c)$$

User and supplier objectives

Also maximizes a guarantee on the consumption.

- Monotonous increasing
- Linked to generation or demand

$$\min_{K,\pi^L,\pi^H} L^G(c)$$

Guarantee loss function: increasing the predictability.
$\Rightarrow$ forecast still as good, but error compensated by users

Solution concept

User cost for one price setting

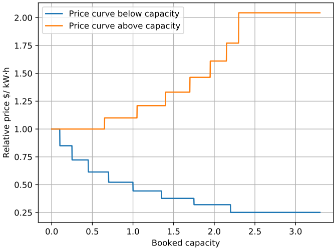


Figure: Higher and lower tariff curves

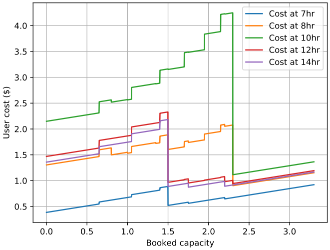


Figure: User cost vs booked capacity

Elements of bilevel and vector optimization

- Multi-objective optimization: ε-constraint to obtain the Pareto set [4]
- Bilevel: optimal value transformation [1] to turn the lower level problem into a set of constraints

Sub-problem definition

- Finite set of capacities potential optima
- Independent of price settings with few conditions
- These candidates are known from both supplier and user

$$S_c = \{0\} \cup C^L \cup \{x_i, i \in I\}$$

Supplier sub-problem at k-th candidate:

$$\min_{K,\pi^L,\pi^H} L^F(K, \pi^L, \pi^H, c_k) \tag{1}$$

$$s.t. \quad L^F(c_k) \geq L^F(c_m) + \delta_u(c_k)\ \forall m \in S_c \backslash \{k\} \tag{2}$$

Building the Pareto front

L^G monotonous decreasing with c

1. Starting from highest possible candidate
2. Compute L^F, L^G
3. If L^F not better than all previous points $\rightarrow$ dominated point
4. Continue for all points

Numerical results

Residential power consumption dataset

Study on 47-month household consumption measurement data [3]

- Aggregation per hour
- Probability discretization using Kernel Density Estimate

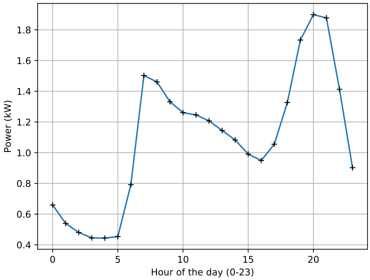


Figure: Average consumption

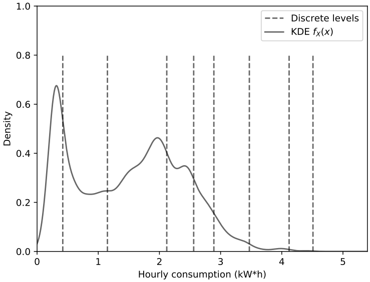
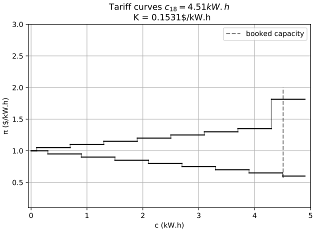
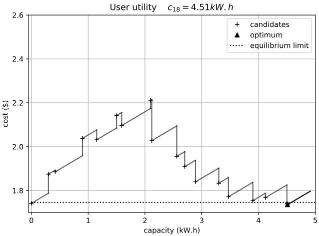


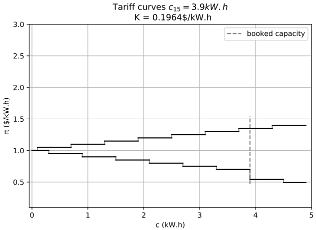
Figure: Discretization at 7AM

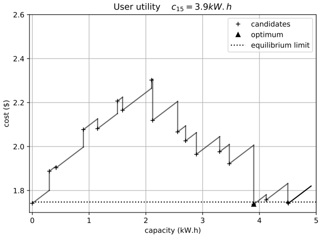
Numerical resolution: Pareto-optimal solutions

Resolution using Julia, JuMP and the Coin-OR LP solver
Pareto-optimal solutions examples:









Resolution: influence of δ and β

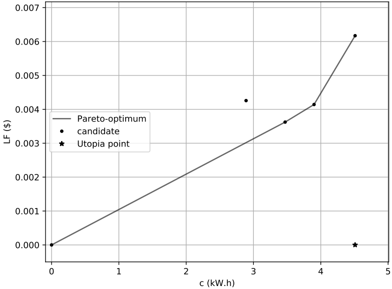


Figure: Discrete Pareto front and sub-problem candidates

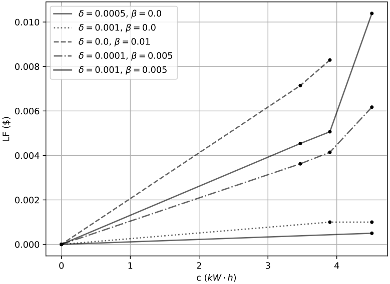


Figure: Pareto front variation with (δ, β)

Further work and extensions

Further work and extensions

- Booked capacity as maximal power in the time frame instead of energy.
- Load shifting & reduction possibility for users
- Match L^G to generation costs
- Handle continuous load probability distributions

Conclusion

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- Reduction of a bilevel, discontinuous, multi-objective problem into a set of LPs
- Simple framework with minimal user action required
- User always have to the option to opt-out for any time-frame ($c = 0$)
- For supplier at higher level: guarantees when planning Unit Commitment
- Forecasts can be wrong, but users contribute

References

References I

Stephan Dempe, Vyacheslav Kalashnikov, Gerardo A. Prez-Valds, and Nataliya Kalashnykova.
Bilevel Programming Problems: Theory, Algorithms and Applications to Energy Networks.
Springer Publishing Company, Incorporated, 2015.

Juan A. Gomez-Herrera and Miguel F. Anjos.
Optimization-based estimation of power capacity profiles for activity-based residential loads.
International Journal of Electrical Power & Energy Systems, 104:664–672, jan 2019.

Georges Hébrail and Alice Bérard.
Individual household electric power consumption data set.

Margaret M. Wiecek, Matthias Ehrgott, and Alexander Engau.
Continuous Multiobjective Programming, pages 739–815.
Springer New York, New York, NY, 2016.

Model formulation

$$\min_{K,\pi^L,\pi^H} (L^F, L^G) \tag{3}$$

$$L^G(c) = P_\Omega [X > \hat{c}] \tag{4}$$

$$(\pi^L, \pi^H) \in \Phi \tag{5}$$

$$\hat{c} \in arg \max_c L^F(c, K, \pi^L, \pi^H) \tag{6}$$