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► **To cite this version:**

Mathieu Besançon, Luce Brotcorne, Miguel Anjos, Juan Gomez-Herrera. Increase in power demand guarantee: a bilevel approach. Optimization days, May 2018, Montréal, Canada. hal-01971748

HAL Id: hal-01971748

<https://hal.inria.fr/hal-01971748>

Submitted on 7 Jan 2019

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Increase in power demand guarantee: a bilevel approach

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8th May 2018

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Outline

Introduction

Time-and-Level-of-Use tariff

Bilevel formulation

Solution concept

Numerical results

Further work and extensions

Conclusion

References

Introduction

Introduction

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

User cost = Booking cost + 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:

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

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.

⇒ forecast still as good, but error compensated by users

Solution concept

User cost for one price setting

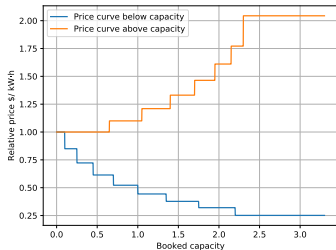


Figure: Higher and lower tariff curves

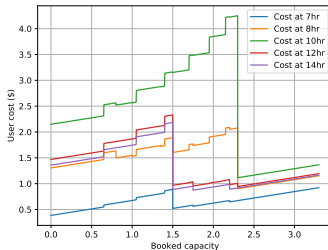


Figure: User cost vs booked capacity

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:

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

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

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

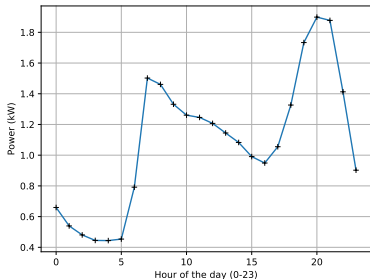


Figure: Average consumption

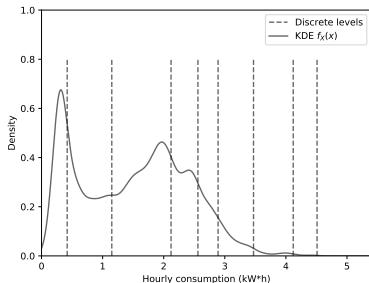
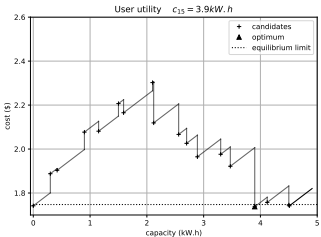
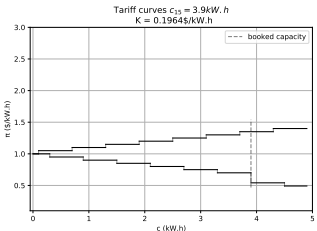
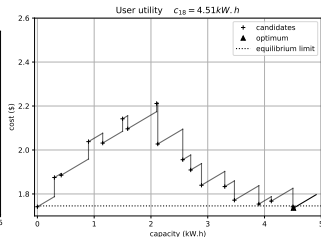
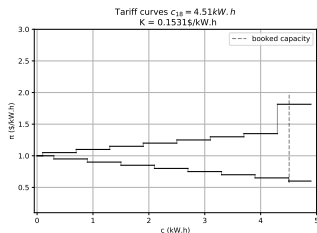


Figure: Discretization at 7AM

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

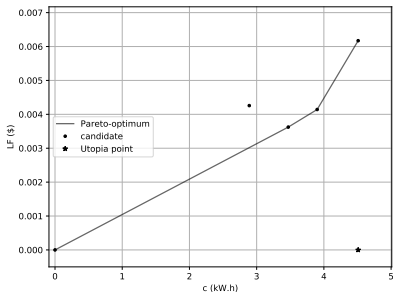


Figure: Discrete Pareto front and sub-problem candidates

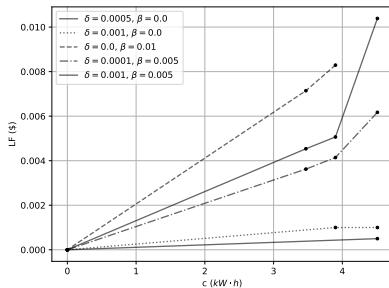


Figure: Pareto front variation with (δ, β)

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

Conclusion

- ▶ 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

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Model formulation

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

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

$$(\pi^L, \pi^H) \in \Phi \quad (5)$$

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