A computationally efficient algorithm for the provision of a day-ahead modulation service by a load aggregator

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Abstract

In this paper, we study a decision making problem faced by an aggregator willing to offer a load modulation service to a Transmission System Operator (TSO). In particular, we concentrate on a day-ahead service consisting of a load modulation option, which can be called by the TSO once per day. The option specifies the maximum amplitude of a potential modification on the demand of the loads within a certain time interval.

We consider the specific case where the loads can be modeled by a generic tank model whose inflow depends on the power consumed by the load and outflow is assumed to be known the day before for every market period. The level of the reservoir at the beginning of the market day is also assumed to be known.

We show that, under these assumptions, the problem of maximizing the amplitude of the load modulation service can be formulated as a mixed integer linear programming problem (MILP). In order to solve this problem in a computationally efficient manner we introduce a novel heuristic-method. We test this method on a set of problems and demonstrate that our approach is orders of magnitude faster than CPLEX - a state-of-the-art software for solving MILP problems - without considerably compromising the solution accuracy.

Introduction

Context :

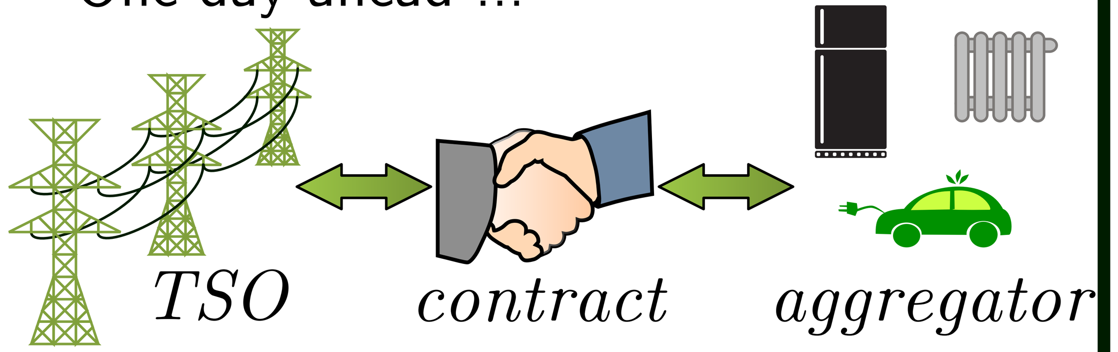
Load aggregator : *trade the flexibility in the demand of a large group of electricity consumers via energy and reserve markets.*

Objective of the aggregator :

- Knowing the quantity of modulation it can sell
- Determining the load management strategy to adopt to maximize this quantity

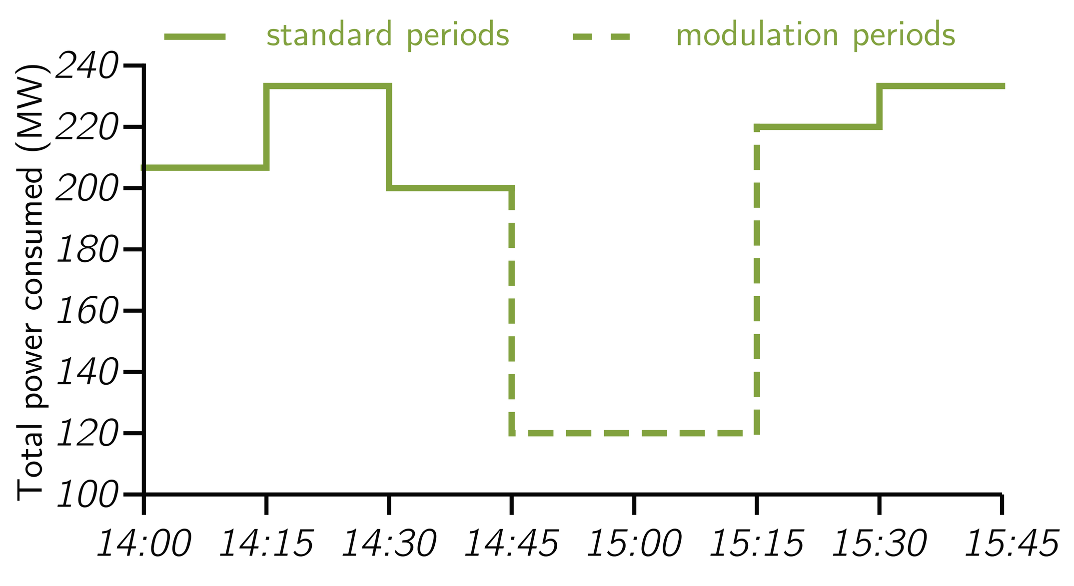
Modulation service

One day ahead ...



- The TSO can demand a modulation at any time in the next day
  - ➡ modulation at the next market period
- The contract specifies :
  - ➡ the maximum quantity of load modulation
  - ➡ the duration of a load modulation.

Modulation Example

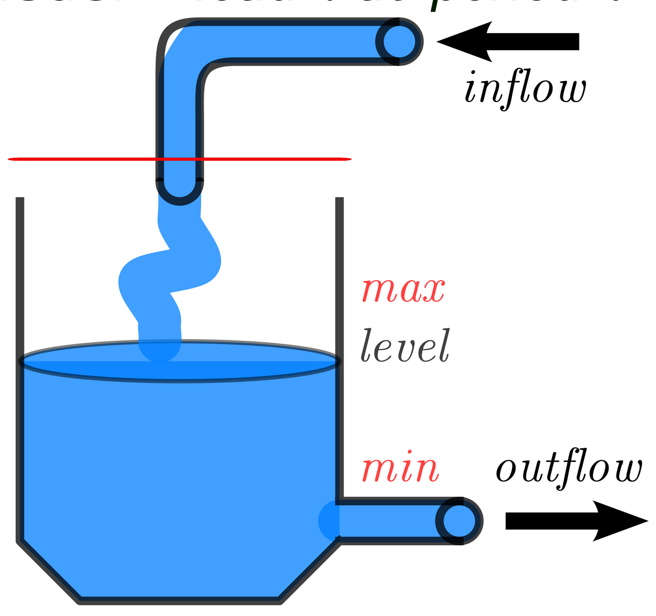


14:40 : TSO notification, **-80 MW**

14:40-14:45 : Aggregator's total consumption : **200 MW**

14:45-15:15 : Modulation of the total power consumed by the aggregator to **120 MW**

Load model - *load i at period t*



Parameters :

- Minimal $l_{i,t}{}^{min}$ and maximal $l_{i,t}{}^{max}$ tank level
- Outflow $\phi_{i,t}$
- Minimal $p_{i,t}{}^{min}$ and maximal $p_{i,t}{}^{max}$ electrical power if the load is activated
- Delay δ_i between electrical power suply and its inflow effect
- Two linearisation, $a_{i,t}$ and $b_{i,t}$, establishing the link between the inflow and the electrical power

Variables :

- Power consumed by the tank $p_{i,t}$
- Level of the tank $l_{i,t}$
- $on_{i,t}$ binary variable equals to 1 if the tank $p_{i,t}>0$

Level evolution :

$$l_{i,t+1} = l_{i,t} - \phi_{i,t} + (a_{i,t-\delta_i}\, p_{i,t-\delta_i} + b_{i,t-\delta_i})\, on_{i,t-\delta_i} \quad (1)$$

Example : heater

- *Tank of temperature*
- *outflow correspond to the loss of temperature*
- *Minimal and maximal level are given by thermostat lower and upper set-points*

Mixed integer programming model

- M loads, T periods, N modulation periods.
- Index j refers to a modulation occurring at period j
- The case where no modulation occurs is given by index 0
- The maximization of the upward modulation quantity can be expressed as the following optimization problem :

$$\max \Delta P^+_{\max} \quad (2)$$

subject to : for $j = 1, ..., T-N$, $t \in \{j+1, ..., j+N\}$,

$$\sum_{i=1}^{M} p^{(j)}_{i,t} = \sum_{i=1}^{M} p^{(j)}_{i,j} + \Delta P^{(j)}_t \quad (3)$$

$$\Delta P^+_{\max} < \Delta P^{(j)}_t \quad (4)$$

for $i = 1, \ldots, M$, $j = 0, \ldots, T-N$, $t = \delta_i, \ldots, T+1+\delta_i$,

$$l^{(j)}_{i,t+1} = l^{(j)}_{i,t} - \phi_{i,t} + a_{i,t-\delta_i} p^{(j)}_{i,t-\delta_i} + b_{i,t-\delta_i} on^{(j)}_{i,t-\delta_i} \quad (5)$$

for $i = 1, \ldots, M$, $j = 0, \ldots, T-N$, $t = 1, \ldots, \delta_i - 1$,

$$l^{(j)}_{i,t+1} = l^{(j)}_{i,t} - \phi_{i,t} \quad (6)$$

for $i = 1, \ldots, M$, $t = 1, \ldots, T+1+\delta_i$, $j = 0, \ldots, T-N$,

$$l^{min}_{i,t} \le l^{(j)}_{i,t} \le l^{max}_{i,t} \quad (7)$$

$$p^{min}_{i,t} on^{(j)}_{i,t} \le p^{(j)}_{i,t} \le p^{max}_{i,t} on^{(j)}_{i,t} \quad (8)$$

for $i = 1, \ldots, M$, $t = 1, \ldots, T+1+\delta_i$, $j = 1, \ldots, T-N$ such as $t \le j$,

$$l^{(j)}_{i,t} = l^{(0)}_{i,t} \quad (9)$$

$$p^{(j)}_{i,t} = p^{(0)}_{i,t} \quad (10)$$

$$on^{(j)}_{i,t} = on^{(0)}_{i,t} \quad (11)$$

and $l^{(j)}_{i,t}$, $p^{(j)}_{i,t}$, $\Delta P^{(j)}_t$, $\Delta P^+_{\max}$ continuous, $on^{(j)}_{i,t}$ binary.

- The optimisation model related to the maximisation of the range of load modulation, has the following objective function:

$$\max \left(\Delta P^+_{\max} + \Delta P^-_{\max}\right) \quad (12)$$

+ additional constraints for the downwards modulation service.

Heuristic algorithm

Algorithm description

1) Feasibility check & level bound improvement

2) Initial activation scheme computation

- For each period, we choose a portion λ_t of the total power Θ_t that can be consumed by the group of loads.

$$\Theta_t = \lambda_t \sum_{i=1}^{M} p^{\max}_{i,t} \quad (13)$$
$$\lambda_t \in [0,1]$$

- Sort the loads and activate them until we consume Θ_t , the remaining ones are switched off.
- Get a feasible solution by changing the power consumed at previous periods by the loads which are in an infeasible state.

3) Extension of the activation scheme to every scenario

- For each scenario j, we take the solution of the step 2 and change it in the periods $j,..,j+N$.
- For an upward modulation, we try to activate every load at their maximal power in these periods.
- For a downward modulation, we try to switch off every load.

4) Local search

- Initially, $\lambda_t = 0.5$ for all t.
- At each iteration, we find the lowest quantity of modulation and its period. We increase/decrease λ_t to improve the solution.

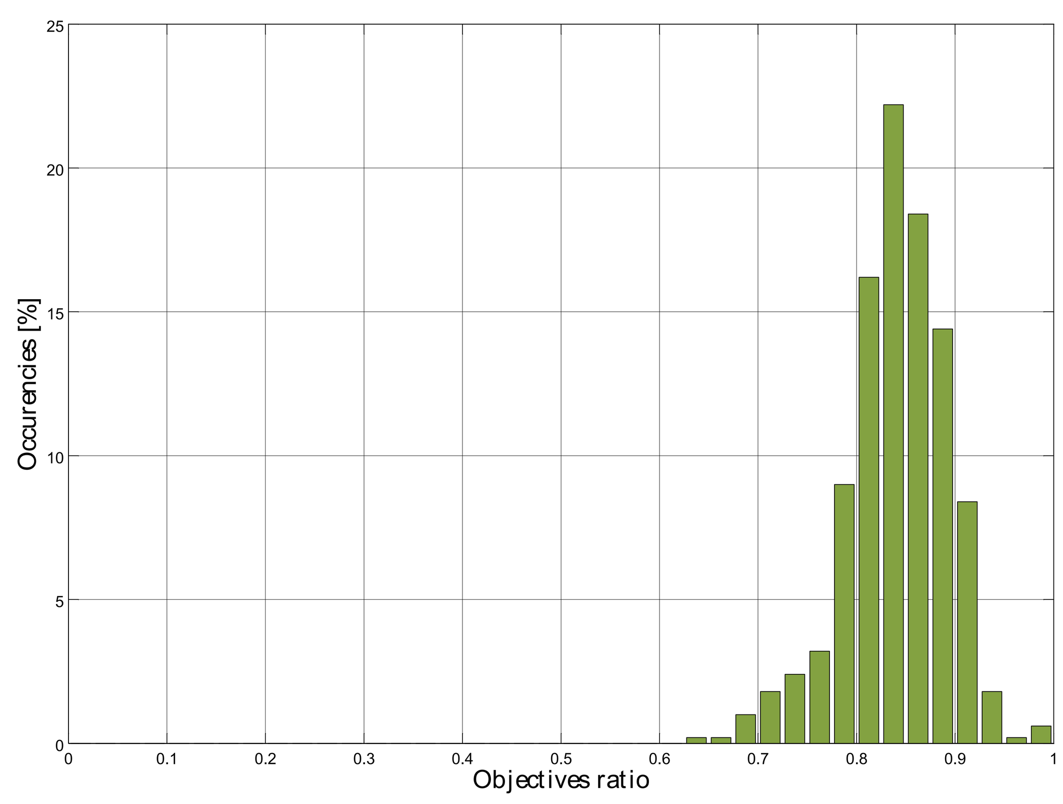
Complexity - *worst case*

$$MT\, log(M) + MT^3 \quad (14)$$

Results

Comparison V.S. *CPLEX*

- 500 problems with 24 periods of 1 hour and 100 loads - small problems to be able to solve them with *CPLEX*
- We compare the ratio : $\Delta P^+_{\max} + \Delta P^-_{\max}$
- For 80% of the problem instances, the ratio is higher than 0.8 and never drops below 0.6
- Even for such small problems, the heuristic algorithm is much faster



Future work

- Validation of the load model
- Alternative load models (non linear ?)
- Modeling of the payback effect following the delivery of a load modulation
- Management of the uncertainty
- Modulation capicity traded for every single period
- Algorithm improvements