PGMO-IROE Project LASON2 2014-1604H Centralized versus Decentralized Energy Management in a Stochastic Setting

Bernardo Kulnig Pagnoncelli* and Michel De Lara†

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Abstract

The LASON2 project seeks to foster research on Centralized and Decentralized Energy Management in a Stochastic Setting, with the purpose to tackle smart grid issues. The LASON2 project is a PGMO-IROE Project funded by Programme Gaspard Monge pour l'Optimisation et la recherche opérationnelle (PGMO) Électricité de France (EDF) et Fondation Mathématique Jacques Hadamard (FMJH) for the years 2014 and 2015.

Link: `http://www.fondation-hadamard.fr/PGMO`

1 The LASON2 project

The Latin American Stochastic Optimization Network (LASON) was formed in 2012 to apply for a PGMO project covering energy applications using stochastic programming, stochastic control, and dynamic programming techniques. The goals of the group were to animate a network of researchers in Chile and France, with similar interests, to study and understand the relevant problems faced by EDF and to attract EDF researchers to collaborate with our team. LASON won two PGMO projects and, after two meetings (January 2013 and December 2013), the group matured and accomplished the goals that were initially proposed.

As a consequence, we have decided to apply to an IROE project with the incorporation of EDF researchers Anes Dallagi and Sandrine Charousset. In the meetings and throughout the year 2013, LASON members have been discussing with EDF researchers the most relevant problems in energy management and how the expertise of the team could be used to address these problems.

*School of Business, Universidad Adolfo Ibáñez, Santiago, Chile. Email: `bernardo.pagnoncelli@uai.cl`
†École des Ponts ParisTech, Université Paris-Est, CERMICS. Email: `delara@cermics.enpc.fr`

Motivated by two EDF reports by Yassine Ameur (advised by Pierre Carpentier and Sandrine Charousset) and Alex Ringeval (advised by Michel De Lara and Sandrine Charousset), that were extensively discussed within the LASON group, the classes of problems we want to handle are related to the challenges posed by the emergence of new local actors in the context of smart grids. More specifically, the recent appearance of small (but relevant) local generators and consumers, which form what we will refer to as Smart Decision Centers (SDC), challenges the classical generation model in which a central planner is the sole decision maker and relevant actor.

New mechanisms of communication between the central planner and SDCs will need to be designed, and, in order to operate the system efficiently, new mathematical formulations have to be developed. Moreover, SDCs are extremely diverse: some have solar panels, wind energy, batteries to store energy, or a combination of those. Hence, assessing the impact of each SDC requires appropriate modeling of their characteristics. What are the objectives of each player? How do they respond to signals (e.g. price changes) set by the regulation authority? How can we capture the uncertainties such as demand, wind generation and prices, in order to construct a useful model?

We believe that the collaboration with a group outside France (and Europe) is fruitful and enriching since it allows the transfer of expertise and a fresh and different view to a very relevant problem faced by EDF. LASON is applying for 2-year IROE project (LASON2) to study the change in paradigm from centralized to decentralized energy systems. There are two parallel problems that the group plan to study. We now describe each of those problems and a yearly plan for each one:

Problem I — Mechanism design

Year 1: Comprehension of the problem and study different mechanisms to model the relationship between the central planner and the local generators. Propose mathematical formulations for the problem, run simulation models that test different mechanisms and different signals that can be sent by the regulation authority.

Year 2: Propose efficient algorithms to solve the resulting problems and integrate the models with part II of the project.

Problem II — Managing and optimizing local generators

Year 1: Comprehend the specifics of each type of SDC. Start designing mathematical formulations for the SDC problem. Develop more sophisticated formulations for SDCs, discuss the different objectives such as cost, environmental goals, reliability of the network, welfare of the population served by the SDC.

Year 2: Develop simulation and optimization algorithms to solve the SDC problem, and integrate the findings with the models in part I of the project.

2 Current members

Chilean Researchers:

1. Bernardo Kulnig Pagnoncelli (Project Director) - Universidad Adolfo Ibáñez, Santiago, Chile, Web page: `http://bernardokp.uai.cl/`, Email: `bernardo.pagnoncelli@uai.cl`

2. Tito Homem-de-Mello - Universidad Adolfo Ibáñez, Santiago, Chile, Web page: `http://mansci-web.uai.cl/~thmello/`, Email: `tito.hmello@uai.cl`

3. Rodrigo Carrasco - Universidad Adolfo Ibáñez, Santiago, Chile, Web page: `http://www.uai.cl/docentes/rodrigo-carrasco`, Email: `rodrigo.carrascos@uai.cl`

French Researchers:

1. Michel de Lara (Project Director in France) - CERMICS, Ecole des Ponts ParisTech, Web page: `http://cermics.enpc.fr/~delara/`, Email: `delara@cermics.enpc.fr`

2. Pierre Carpentier - UMA, ENSTA ParisTech, Web page: `http://www.ensta-paristech.fr/~pcarpent/`, Email: `pierre.carpentier@ensta-paristech.fr`

3. Jean-Philippe Chancelier - CERMICS, Ecole des Ponts ParisTech, Web page: `http://cermics.enpc.fr/~jpc`, Email: `jpc@cermics.enpc.fr`

EDF Researchers:

1. Riadh Zorgati, Email: `riadh.zorgati@edf.fr`

2. Sandrine Charousset, Email: `sandrine.charousset@edf.fr`

Students:

1. Valentin Foucher, École Polytechnique, Paris, France.

3 Workshops (past and future meetings)

3.1 Chile workshop, Santiago, Wednesday 17 — Tuesday 18, December 2014

3.2 France workshop, Paris, Monday 22 — Friday 26, June 2015

4 Problem formulations

At the current stage, we are formulating the problems we plan to attack within the framework of the project. Given the complexity of the subject, and the difficulties associated with converting all the elements of a smart grid into a mathematical problem, we found it useful to have a series of simple problems that will serve as basis for our work. The plan is to progressively add more features to these problems with the final goal of producing realistic instances that can serve as decision support tools to EDF.

4.1 Energy management in a microgrid

A microgrid is a small-scale unit of energy generation, storage and loads that can function autonomously. The microgrid is connected to the centralized system, from which it consumes energy when needed, and can sell the excess that was generated when it is convenient.

We present a simple model of a small photovoltaic microgrid with batteries as storage connected to the main power grid. The indexes $t = 1, \ldots, 24$ represent the hours of a day, $S = 1, \ldots, S$ are the scenarios and $n = 1, \ldots, N$ are the nodes of the network. The variables of the model are:

- Energy consumed from panels (XP), from batteries (XB), and from the network (XR).
- Energy injected into the network from panels (YP) and from batteries (YB).
- Energy stored in the battery generated from panels (ZP) and from the network (ZR).
- Slack variables $U_t^{n,s}$ and $O_t^{n,s}$ capture an underestimation and an over estimation in the energy generated by the panel.

The parameters of the model are

- $G_t^{n,s}$: random energy generated by the panel.
- D_t^n : demand os the users.
- VR_t^n : sale price of energy from the network.
- VI_t^n : sale price of energy to the network.
- K: storage capacity of the battery.
- K_c maximum charge capacity of the batteries.
- K_d maximum discharge capacity of the batteries.

$$\min_{C_n} \sum_{n \in E} p_n \cdot C_n$$

$$\begin{aligned}
&\text{s.t.}\\
&\quad XP_t^n + XB_t^n + XR_t^n = D_t^n \quad \text{(consumption)}\\
&\quad XP_t^n + YP_t^n + ZP_t^n - O_t^{n,s} + U_t^{ns} = G_t^{n,s} \quad \text{(generation)}\\
&\quad K_t^n = K_{t-1}^n + \alpha(ZP_{t-1}^n - ZR_{t-1}^n) - (YB_{t-1}^n + XB_{t-1}^n) \quad \text{(battery storage)}\\
&\quad K_t^n \le \alpha K \quad \text{(battery capacity)}\\
&\quad \alpha(ZP_t^n + ZR_t^n) \le \alpha \text{kcw}, \quad \alpha(XB_t^n + YB_t^n) \le \alpha \text{kdw} \quad \text{(battery charge/discharge)}
\end{aligned}$$

The formulation was originally proposed by S. Vojkovic, I. Weber and R. Carrasco.

4.2 Demand response

Demand response consists changes in the pattern of energy use by consumers in response to changes in the way energy is charged. Companies might offer incentives to *demand shedding*, which essentially means consumers will reduce their consumption of certain utilities. In other cases there might be a *demand shifting*, which only alters the time window that consumption will occur. The typical example are washing machines. Finally, there is the non-moveable demand, which offers no flexibility for the utility company.

We propose a model that considers two closely related problems: the utility company problem and the client's problem. Let us define the relevant variables. The total load for user i at time t is given by

$$q_{it} = q_{it}^{(d)} + q_{it}^{(s)} + q_{it}^{(n)},$$

where $q_{it}^{(d)}$ is the sheddable load, $q_{it}^{(s)}$ is the shiftable load and $q_{it}^{(n)}$ is the non-moveable load. Each user i at time t will be asked to shed $y_{it} \leq q_{it}^{(d)}$ of its load, receiving a compensation $p_{it}^{(d)}$ per unit of load shed. The user suffers a discomfort $D_i(y_{it})$ for shedding the load, which we assume as a quadratic function.

For shiftable loads, each user i accepts shifting the use of appliance j to the time window $[\alpha_{ij}, \beta_{ij}]$. The decision variable x_{ijt} denotes consumption at time t, and is equals to zero if t is outside the pre-specified interval. The utility company will bill customers

$$B_{it} = B^f \left(q_{it}^{(s)} + q_{it}^{(d)} - y_{it} \right) + B_t^s q_{it}^{(n)},$$

where B^f and B_t^s are constants. The utility company will purchase energy from the day-ahead market at cost C_t^{dam} and from the spot market at a cost C_t^{rtm}. The total cost of producing energy is thus

$$C_t = C_t^{dam} \left(Q_t^{(d)} - Y_t + Q_t^{(s)} + \tilde{Q}_t^{(n)} \right) + C_t^{rtm} \left(\left(Q_t^{(n)} - \tilde{Q}_t^{(n)} \right)^+ \right),$$

where $Q_t^{(d)}, Q_t^{(s)}$ and $Q_t^{(n)}$ are the shedding, shiftable and non-moveable demands. The problem for the utility company can be written as follows:

$$\max_{X,Y,\tilde{Q}_t^{(n)}} \sum_t \sum_i B_{it} - p_t^{(d)} y_{it} - C_t$$

$$\begin{aligned}
&\text{s.t.:}\\
q_{it}^{(s)} &= \sum_j x_{ijt}, \forall t, \forall i,\\
\sum_t x_{ijt} &= \hat{x}_{ij}, \forall j, \forall i,\\
x_{ijt} &= 0, \forall j, \forall i, \forall t \notin [\alpha_{ij}, \beta_{ij}],\\
y_{it} &\geq 0, \forall t, \forall i,\\
y_{it} &\leq q_{it}, \forall t, \forall i,\\
x^{ijt} &\geq \underline{x}_{ij}, \forall t, \forall j, \forall i,\\
x_{ijt} &\leq \overline{x}_{ij}, \forall t, \forall j, \forall i.
\end{aligned}$$

This formulation computes the optimal shedding and shifting strategies, but assumes the demand for non-moveable utilities and the spot market prices are known. There are several ways possible ways to deal with uncertainty for this problem. Our initial approach was to use robust optimization.

Let us now state the client's problem:

$$\min_{x_i, y_i} \sum_{t=1}^{T} B_{it} + D_{it}(y_{it}) - p_{it}^{(d)} y_{it}$$

$$\begin{aligned}
q_{it} &= \sum_j x_{ijt}, \forall t,\\
\sum_t x_{ijt} &= \tilde{x}_{ij}, \forall j,\\
x_{ijt} &= 0, \forall j, \forall t \notin [\alpha_{ij}, \beta_{ij}],\\
y_{it} &\geq 0, \forall t,\\
y_{it} &\leq q_{it}^{(d)}, \forall t,\\
x_{ijt} &\geq \hat{x}_{ij}, \forall t, \forall j,\\
x_{ijt} &\leq \hat{x}_{ij}, \forall t, \forall j.
\end{aligned}$$

The utility can affect the solution of the client's problem by modifying the compensation $p_{it}^{(d)}$ offered. In order to solve the problem, we propose an iterative algorithm that solves the utility and client's problems iteratively, First, in a shedding step, the optimal shedding strategy is computed given the current compensation rate. Next, the compensation and shifting strategies are computed, solving the client's problem.

The formulation was originally proposed by R. Carrasco, I. Akrotirianakis, A. Chakraborty.