

Gaspard Monge Program for Optimization, operational research and their interactions with Data Sciences



2017 Call for projects
IROE appendix
lcode appendix

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1 Introduction

This paper aims to describe in details some of the problems of energy management, and to give an idea of the work already completed or in progress on these topics, and the main difficulties already encountered. The listed research directions are given as an example. The submitted projects may address other issues than those listed below or consider methods of resolution that are completely different or that are a continuation of the works quoted.

Proposers are strongly encouraged to contact the experts at EDF R&D on each subject in order to have a thorough knowledge of the issues and research works already done or committed on each topic. For this, thank you to contact the PGM board (mailto: pgmo@fondation-hadamard.fr).

2 Background: the main issues in Energy Management

2.1 Managing the Supply-Demand balance

In order to generate electricity, a diverse portfolio of physical and financial assets (supply) is available in order to meet the customers consumption (demand). The balance between supply and demand must imperatively be reached at each time period in order to avoid the risks of physical system failures. The objective of Generation Management is to achieve this balance at minimal cost.

2.1.1 Uncertainties

Many uncertainties significantly impact the management of production either from the point of view of system safety than from the economic point of view. These uncertainties are mainly due to climate (temperature -which strongly influences the demand for electricity-, hydraulic inflows, wind, cloud cover, sun), outages of power plants, prices on the energy markets, renewable production (wind and photovoltaic). Those uncertainties are strongly correlated one to each others.

2.1.2 A diversified generation and flexibility assets portfolio

The physical offer comprises all generation or flexibility assets, including load management. It includes both traditional centralised assets and distributed assets. Centralised means connected to the transmission network. Centralised assets are generation units (power plants incl. renewables, hydro valleys), demand management, multi-energy assets and storages. Distributed means connected to the distribution network. Distributed assets are generation units incl. renewables, load management, electric mobility, storages and multi-energy assets. Distributed assets may be aggregates of elementary asset with diverse representation of aggregation (aggregators).

- **Thermal assets**, consisting of nuclear and conventional thermal power plants: coal, oil, gas turbines, GCCs. Each plant has to respect a set of constraints (production ranges, minimum periods stop or run, start-up curves, possibly common fuel stock to several plants, ...) and is characterized by a complex cost structure (fixed costs or depending on the amount of fuel, startup costs ...), specific contributions to ancillary services, emissions, ...
- **Hydraulic assets**, consisting of hydraulic plants (including pumped storage) located in valleys with water route between plants whose duration vary depending where the plants are located, constraints on reservoirs (minimum and maximum volumes, water values...) and plants (power limitations, discrete operating points, gradient constraints, change of direction constraints, flow delays, water head effects ...).
- **Intermittent renewable generation** : wind, solar...
- **Electricity load**, including not flexible demand and flexible demand (e.g. load shifting) both centralized and distributed.
- **Distributed and centralised storages**.
- **Aggregators** i.e., actors that provide aggregation services through the management of a set of distributed assets (generation, storage, demand response through contracts with some customers...).

- **Multi-energy assets** can provide flexibilities to the electricity system (power-to-gas, power-to-heat...)

2.1.3 Markets

- Electricity and commodities spot markets
- Future markets
- Capacity markets
- Intra-day markets....

2.1.4 Environmental constraints

The directives and guidelines initiated by the European Union in order to foster a general approach against climate change and for environmental protection have a strong impact on the management of the supply-demand balance for energy producers:

- control of greenhouse gas emissions: management of pollutant emission;
- taking the increase of the renewable generation (wind, photovoltaic ...) into account, inducing high uncertainties.

2.2 The challenges : Manage a diversified portfolio of very large size

The goal is to manage the portfolio (generation assets and contracts) in the objective of minimizing costs while considering uncertainties. This problem is not solvable in the present state of knowledge, because of its very large size and its mathematical complexity. It then has to be decomposed into a set of problems per time horizons on the following principle: at distant time horizons, the most important hazards (weather hazards, hazards on the operation of power plants, market risks ...) are represented very accurately (in practice as random process or a very large number of scenarios), while the generation assets are briefly described, and vice versa, at close time horizons generation assets are described very precisely, but uncertainties are not represented.... Each time horizon provides a set of indicators for the closer time horizons, in order to give a vision of the future and to keep all this coherent.

At each time horizon, optimization problems remain, however, very large, leading to a particular difficulty related to computing time, because the operating process has to comply with strong planning constraints.

2.2.1 Long-Term

In the long term (five to twenty years), the questions are:

- simulate the evolution of prices of fuels and electricity, which are based on the calculation of underlying fundamentals, ie, a model of the supply-demand balance over a set of interconnected geographical areas;
- plan investments in new generation assets. Investment planning methods are based on a minimization of the supply-demand balance cost, the result being the optimal (and robust to uncertainties like physical hazards, economic and regulatory uncertainties) distribution of technologies to meet base and peak demand.

More details may be found in [LAB2011].

2.2.2 Mid-Term

In the mid-term (one to five years), the questions are:

- **Defining the optimal outage schedules for refueling the nuclear reactors**, in order to minimize generation costs while satisfying a number of constraints on either the generation of each reactor, the dynamic constraints of each reactor and constraints on the dates of the outages (earlier or later dates, minimum/maximum spacing or recoveries between outages ...), this regarding numerous uncertainties. A detailed description can be found on the PGMO web site and in [ROAD2010].
- **Defining coordinated management strategies for a set of stocks** (lakes, fuel stocks, stocks of "effacements", pollutant emission stocks): the aim is to calculate optimal strategies that adapt themselves to uncertainties (feedback, "multi-stage" with recourse, ...). One of the main issues is

relative to the joint optimization of all stocks. Currently, difficulties appear beyond three stocks due to the limitations of the techniques used (dynamic programming). In addition, the uncertainties models are not very accurate, which raises many questions of how to describe those hazards in the optimization problem. (see [L2008], [G2010] for more details).

2.2.3 Short-Term

In the short-term (a few days to a few hours), the questions are to define a day-ahead production planning and to adjust near real-time schedules to meet the actual demand. The main issues are:

- Calculate minimum cost generation schedules for the next day, complying all constraints on generation assets, meeting the demand constraint (power and reserves) while providing recourse schedules in order to take into account future uncertainties.
- Optimize Intra-Day rescheduling (“redeclarations” in French): at each hour of the day, the producer must change the schedules of a limited number of assets (thermal assets or parts of hydro-valleys) in order to reduce the real-time production-consumption gaps due to uncertainties on demand and availability of assets.
- Calculate generation margins and optimize reserves.
- Calculate balancing offers for the adjustment market.

More details are available in [HBML2010]. A very detailed description of the problem, as well as presentations explaining the state of the art on this issue are available on the PGMO web site.

3 IROE Main research topics

The list of all already funded PGMO projects may be found on the PGMO web site.

3.1 Fundamentals and Investments

3.1.1 Fundamentals (long-term)

Fundamentals models are designed to calculate the long-term prices of energies on a set of interconnected areas. In the case of electricity, the main difficulties comes from the representation of the various stock management strategies, water in particular, and from the representation of the transmission network. The mathematical model associated with these issues is a problem of economic stability across Europe, each country aiming at minimizing its costs while providing energy to its customers and contributing to the global European equilibrium. Balance prices calculated with this model can be interpreted as price indicators of electric energy.

The main methods that are currently investigated are related to decomposition.

A recently proposed method is to solve this problem using a quantities-decomposition algorithm associated with an SDDP algorithm for optimising the reservoirs management strategies [LBD2012].

See also the PGMO projects “Proximal decomposition of stochastic programs for long-term multi-zonal generation management”, “Long-term planning of interconnected generation”

3.1.2 Investments

The issue of this problem is to determine the technologies in which it will be best to invest in the future in order to meet energy demand. Due to the nature of those investments (construction of a plant, modification of the network, ...), it is necessary to anticipate them far in advance. In other words it is necessary to take all relevant information necessary into account to determine the right sizing of production facilities on the horizon 15-20 years, such as: changes in the price of fundamentals (fuel prices ..), the evolution of energy demand, or assumptions related to the energy policy in Europe.

This problem may be seen as an extension of the fundamentals problem, where investments are decision variables.

We can refer to [G2014] for more details and a description of the work already done on this subject. Formulations of the problem have been proposed and are available. ***This problem is one of the topics of great interest to this call for projects.***

3.2 Centralized vs Decentralized Optimization, local actors

The energy systems in Europe have originally been designed in order to reach the best possible economical objective in each country for satisfying a given demand. Economy of scale principles were applied and lead to build a mix mainly composed of large generation assets. Moreover, a centralised generation mix was seen to be the best solution to serve demand, as through centralisation it is possible to aggregate multiple very uncertain and variable demands and thus reach a relatively stable global demand.

The emergence of a high share of intermittent renewable energy sources in the energy system leads to many difficulties, due to their characteristics (intermittent, hardly predictable, usually non flexible, usually not contributing to frequency stability services, spread all over the territory, not always close to demand, connected to the distribution network thus constrained by its size).

Furthermore, recent and forthcoming regulatory and technical evolutions will deeply transform the system with the upcoming local demand management tools and a more proactive stance of actors in the field, including customers.

Therefore the energy management tools will need to change significantly and contributions to flexibility will gain “significant” value which will make their precise valuation primordial.

3.2.1 Centralized Optimization

The generation management process at mid-term-term horizons of energy is conventionally done in France in a centralized way. This problem has been studied for many years and various approaches have been proposed around stochastic decomposition methods applied to the mid-term optimization problem of an electricity generating facilities subject to a supply-demand equilibrium coupling constraint within a stochastic framework:

approaches based on decomposition methods, stochastic optimal control, dynamic programming... (See [E2008], [L2008], [B2004], [D2006], [CCD2009], [RS2011], [BCG2010], [G2010], [A2013]).

'Centralised' optimization is still useful in the sense that a central coordination will provide a general target of the optimum; A centralised point of view can also be used for simulating a market mechanism.

3.2.2 Decentralised Optimization

Decentralised Optimization covers many interesting problems :

- Integrated optimization. Integrated optimization means that all generation/flexibility means in a specific geographic frame are considered, either with a 'centralised' point of view or not. New constraints and mechanisms are to be dealt with
- Optimization of local players. Looking at a local level, new problems appear, which are related to the emergence of local players. They are facing local specific constraints (among them those coming from the distribution network) The modeling of these problems, especially in a context of intermittent energy is a topic in itself.
- Relationships between centralized power system management (supply-demand balance on a global scale and network balance management) and decentralized management (local management, due to the emergence of new players and means of production: photovoltaic, wind, smart grids, storage ...). Regarding the global supply-demand balance, one can address various questions : i) what are the role and impact of local actors on the centralized management ? ii) What will be the signals that are transmitted between the different actors and how will we model them? iii) how to consider local constraints with a global point of view?
- The emergence of local actors also suggests to consider problems related to (transmission) network and joint 'network-generation-demand flexibilities' optimization problems. (considering mainly the distribution network), and problems relative to modelling the behavior of consumers in a competitive context.
- Moreover, contributions of multi-energy assets will need to be integrated.

This topic is fairly new and deals with issues at different levels of the supply-demand balance process.

Some mathematical approaches were identified including:

- Decomposition Methods
- Bilevel Optimisation,
- Game Theory

See also PGMO Projects "Decomposition/Coordination for Smart Grids", "Smart Methods for the Grid", "Centralized versus Decentralized Energy Management in a Stochastic Setting", "Design and Pricing of Electricity Services in a Competitive Environment", "Decentralized control for renewable integration in smart-grids", "Decentralised optimization and smart-grids"

3.3 Short-term Generation Scheduling

The "Unit Commitment" problem consists of finding a minimum cost operating program for all power plants:

- providing adequate systems services;
- ensuring the supply-demand balance at every half-hour;
- respecting all operational constraints.

3.3.1 Daily and Weekly Optimization

The objective is to determine the optimal generation schedule which minimizes costs (production costs and start-up costs), while meeting exactly the set of "demands" (consumption, reserve capacity and system services) and complying the numerous operational constraints that affect thermal and hydraulic power plants. Solving this problem will determine the day before a reference schedule for the next day.

This Unit Commitment problem is long known, many research studies have already been made. The current solution is a combination of Lagrangian dualization, price-decomposition and bundle algorithms (see [LS1994]). This gives a first schedule which will then be adapted using an Augmented Lagrangian technique combined with the use of the auxiliary problem principle to get the reference schedule (see [CZ1984], [BR1992], [MS1983], [DGL2005]). This solution gives excellent results on the historical deterministic problem.

Recently, the strong increase of "new" renewable energies (wind, solar) forced to rethink the problem. Indeed, if "historical" uncertainties (consumption, water intake, failures) could be neglected on a very short-term horizon, it is no longer the case for these new hazards, due to their high non-predictability characteristic (we have no reliable forecasts beyond a few hours) and their intermittent nature (eg clouds passing moves the photovoltaic generation abruptly to 0). It is essential to address these new phenomena.

- First, to model finely all operational constraints in order to benefit from the flexibility of all production facilities, particularly in hydraulics, leading the introduction in particular of the many non-convex or binary constraints. That detailed modeling of the constraints induces difficulties on the overall resolution of the problem because the sub-problems coming from the prices decomposition become more difficult to solve, so are solved in an approximate way which is not compatible with the traditional algorithm. To solve this problem, a new bundle method capable of dealing inaccurate Oracle was developed. A PGM project (Consistent Dual Primal Signals and Optimal Solutions) aims to improve the resolution by Lagrangian dualization through incorporating heuristics and improving the bundle algorithm. A new line of highly prospective research concerning the non-convex duality and interpretation of dual variables associated is also identified.
- Second, take the uncertainties into account through the calculation of robust production programs, ie where the cost of adapting to the occurrence of intra-day hazards is minimal, so this problem can be formalized as a problem with recourse. Work has been done on a robust approach without recourse decisions, as well as a robust approach with recourse decision but on small convex problems (cf. [BS2011] [Ap2007] [AHMZ2011]). More recently, advances were made through the PhD thesis [A2013b] and a PGM project (optimization under uncertainty for the problems of "Unit Commitment") looking at the real problem is ongoing. An approach based on stochastic optimization using uncertainties trees is also addressed in a PGM project (A Stochastic Programming Approach to Finding Robust Reference Schedules for the Unit Commitment problem). See also PGM project "Optimization & stability of stochastic unit-commitment problems"

3.3.2 Intra-Day Optimization and Re-Scheduling

Regulatory developments have led to formulate a new problem on the Intra-Daily horizon : recalculating production schedules by solving the same problem as above plus a so-called re-scheduling constraint which specifies the maximum number of plants (about 30 out of 150) for which the reference schedule can be changed. This constraint is both coupling and combinatorial. Heuristic methods were considered: the problem is decomposed into a phase of selection of plants in which the schedule will be changed then a phase of optimization of the schedules of these plants.

Work is currently being undertaken around a method consisting in using a supervised learning algorithm to decide the list of plants whose program will be moved and a classic Unit-Commitment problem.

Some "Group Sparsity" approaches are also under investigation (see [ABLEGRZ2014], and the PGM project "Robust Sketching for Structured Multi-Instance Optimization with Uncertainty, Application to Energy Management").

Recent regulatory evolutions may make it necessary to reduce the time steps of the models. Typical timestep in daily/intraday process is 30 minutes which may go down to 15 or even 5 minutes. An answer to these changes may be to have a time continuous model, which may lead to developing completely different optimization methodologies.

See also PGM project "short term replanning".

3.3.3 Margins and Reserves Optimization

The objective is to jointly optimize production programs and reserves, taking into account all the hazards.

3.4 Optimization of hydro-electric valleys

At long and mid-term, the objective is to calculate good management strategies for the valleys, taking some constraints on the reservoir levels into account. In the short term the problem amounts to computing feasible programs (ie satisfying the constraints) in order to allow the use of all flexibilities of the hydraulic park.

3.4.1 Long and medium term

The main difficulty is to calculate the management strategies for coordinated reservoirs while dealing with uncertainties. Some solutions to the classical problem where the reservoirs have to respect a coupling demand constraint already exist. For more complex structures, for instance 'Cascade' eg when it comes to coordinating all the reservoirs of one hydraulic Valley, effective methods are still being defined (see [E2008], [L2008], [B2004], [D2006], [CCD2009], [PDG2011], [VP2011], [RS2011]). The stochastic decomposition method developed in the context of the global supply-demand balance [G2010] has been extended to the case of cascade reservoirs by [A2013].

A formulation with probability constraints (for taking into account the volume probability constraints on reservoirs) was proposed. The resolution method is based on the dualisation of the probabilistic constraint ([A2013]).

3.4.2 Short-term

The main difficulty is to solve accurately and in a very short calculation time a large mixed integer problem, characterized by very strong constraints.

A thesis and a PGMO project (Optimality for Tough Combinatorial Problems Valley Hydro) are working on to solve this problem by combining mathematical methods and combinatorial optimization heuristics. The PGMO project "Decomposition and feasibility restoration for Cascaded Reservoir Management" is ongoing.

Local approaches are also investigated (see PGMO project "Hybrid approaches for solving bi-objective energy problems with low-carbon constraints").

The need to take into account the short-term uncertainties also encourages to solve the problem with taking the hazards into account. A PGMO Project ("Hydro-electric scheduling under uncertainty") aims to combine methods from stochastic optimization and combinatorial optimization.

3.5 Logistics

3.5.1 Routing Problems

The scheduling and routing problem for technician interventions on the electricity distribution networks is difficult and of high interest due to the number of kilometers and mobilized resources (manpower, vehicles and equipment).

This problem can be decomposed in several coordinated stages :

- Strategic : deciding where to settle all sites (ie the premises where the technicians and their vehicles are based), taking into account all different activities organized there, and the site capacity (number of employees, number of vehicles), as well as needs and constraints. When the workload changes, decision makers can explore the interest of reducing or increasing the number of sites and their location, looking at several criteria;
- Operational : determining the daily routing of all technicians of a given site, while meeting the demand (list of operation applications, e.g. maintenance of an electric line...) and taking into account several criteria (distances, equipments that have to be loaded in each vehicles at the beginning of the day, necessary qualifications to perform the operations, ...).
- Real-Time : adjusting the routing schedule to the occurrence of unforeseen events (cancellation, weather ...).

This problem can be seen as a multiple Vehicle Routing Problem with Time Windows. Current work was conducted on a simplified problem (operational stage only), using local search techniques and mixed integer linear programming.

Further researches could focus on the following difficulties :

- Integrating all accurate constraints of operational planning within a strategic planning model, while modeling the evolution of the load.

- Looking at future business needs: touring can be single or multiple ie. taking into account vehicles with only one technician or several technicians. Multi-modal touring : conventional vehicle, electric vehicle, bicycle and / or walking.
- Multi-site problem : technicians of a given site may take in charge operations that are at the border of neighbourhood sites.
- Robust approaches or online optimization for operational planning
- Dynamic readjustment of the touring schedule.

3.5.2 Optimizing maintenance programs

The idea is here to find the schedule that will optimize the Net Present Value of the maintenance program (the NPV is the economic indicator balancing investments cost and benefits created by these investments) while fulfilling various constraints (precedence between investments, limited number of investments, budget limit...).

- What we have: we developed a tool, that use Genetic Algorithm to make this optimization based on an evaluation function that gives expected values through Markov graphs.
- What we would like to have: we would like to be able to make the same optimization based on risk indicators and not only expected values. We have the model to assess these risk indicators based on Monte-Carlo simulation but calculations are too long for usual optimization methods .

The two research areas would then be to works on:

- Simulation-Optimization
- Robust Optimization

3.5.3 Optimizing spare parts stock:

The idea is here to find the number of spare parts that will minimize the global owning cost (sum of purchases and shortage costs).

- What we have: a tool that calculates the global owning cost with a closed-form expression. The "optimization" is made with a greedy algorithm iteratively buying the spare part with the best improvement over cost ratio until budget limit is reached.
- What we would like to have: we would like an optimization algorithm that gives better results than the greedy algorithm and which would be able to deal with budget uncertainty

The two research areas would then be to works on:

- Simulation-Optimization
- Robust Optimization

3.5.4 Algorithm-driven process design

Rational design of chemical and energy processes started at the early 20th century with the emergence of chemical engineering science. Methods evolved through decades including more and more computer assistance as machine and algorithm became available. Today, with the recent development in computer science and applied mathematics, a next step can be foreseen: a process can be fully designed based on algorithm, able to find optimal solution under physical, engineering and regulatory constraints. These approaches start to be developed [W2015] but are not yet applied to real industrial case including its constraints.

The development of 'proof of concept' of such algorithms driven by real industrial system with cost of generation as the objective to be minimized could be of interest, if applied to an already very well optimized and deployed industrial systems (e.g thermal process such as steam cycle or boiler or a specific equipment such as turbine or alternator) in order to be able to assess the real added value of the approach. The key issue to address is how to produce reliable results taking into account constraint linked to engineering constraint efficiently.

3.6 Big size

A general characteristic of all the above problems is their big size, associated to operational needs of fast solving. All methods meant to accelerate the solving of those problems are of interest.

Some ongoing ideas are to try to exploit the fact that the operational process leads to solving a very high number of very close instances.

Online optimization, sketching methods and learning are investigated through PGMO projects “Robust Sketching for Structured Multi-Instance Optimization with Uncertainty, Application to Energy Management”, ‘Reducing combinatorial by using learning methods’

Alternative methodologies would be appreciated.

4 Icode Energy Challenge - Specific Research Topics

Current (and past) electrical system: The French electrical system was designed in the fifties around big installations of productions (hydraulic valleys then nuclear power plants) connected to a highly meshed transport network. This organization allowed a centralized management of the balance between demand and supply with as main criterion the minimization of the total cost. It favored the sharing (fluctuations of consumption and production) and scaling factors (size of the groups of conventional production). The principle of fare adjustment (the same price for all regardless of the distance with a production spot) and the high level of meshing of the network led to manage the production without taking into account the constraints associated with the network. The cost of necessary adjustments (for instance safety ones) was taken into consideration separately.

The sale rate proposed to the customer was initially built according to the principles proposed by Marcel Boiteux: to sell the energy to the marginal cost of production (i.e., at the cost of the last megawatt started) allows one to guarantee the equilibrium of the system. After the oil crisis in the seventies, these principles were complemented with rates allowing to smoothen the peaks of demand: the "EJP" (the electricity price is much expensive some days of the year, inciting the subscribers to lower their load). Thus in the above described framework, decision-making tools have been tailored with the objective to calculate the schedules of functioning of all the power plants of the electrical network, as well as the dates of the EJP, by respecting the constraints of functioning, safety while insuring the balance demand supply. Moreover, these tools also helped decision taking as regards investments in new means of production, dates of stop of nuclear power plants for recharging, the management of lakes (in which period of the year to slog or to pump), the programs half an hour by half an hour over all the power plants and releases of the "EJP".

- **Recent and upcoming evolutions:** a series of changes has recently occurred and we list the most important ones.
- **Technological changes:** (a) communicating meters (such as Linky) which will allow to propose much more differentiated rates and to pilot the whole domestic load. Traditional meters measure only the total energy consumed at the time of the checking and can send only signals day-night. The new meters measure the consumptions hour by hour and can transmit finer signals which, when combined with "boxes", will allow true piloting of domestic uses (reloading of battery-driven vehicle, heating, washing machine, etc.); (b) development of distributed, renewable and fatal production capacities (in particular wind and photovoltaic): contrary to conventional production means, solar power plants and wind turbines are of "small size" and are not connected to the transport network but to the distribution network and thus can be managed in a decentralized way (ex: administrator of wind farm, individuals reselling their surplus of solar energy, ...); (c) development of storage capacity: the electric system was designed with the principle that 'electricity does not store' (except in the form of water). The recent technological evolutions allow distributed storage, which can be managed locally.
- **Societal aspirations:** they are linked to a wish of regaining a public-spirited control of the energy problems, but also to motivation for an active participation of the consumers in these problems. The perception of the system plays an important role, in all its aspects, including fare (important variable part, high taxes).
- **Rationalization of energy systems:** triggered in particular by environmental concerns, it brings to rethink these systems in a wider way, without restricting them a priori to the sole electric one, even to think in terms of services and uses (mobility, thermal comfort) and not of energy vectors and volumes.
- **Regulatory evolutions:** new competitors and the possibility for new incomers to participate in the electric system: (new businesses with wind farms coupled with local storage and many sets of customers associate with specific geographical zones).

As a consequence, these changes impose to completely reshape in the near future the decision making tools driving the management of the electric system and even to invent new ones.

The main research topics within Icode (not excluding the IROE research topics) are :

- Dentralsed/decentralised optimisation (see IROE paragraph)
- Implementation of the piloting of the load via the offers to the customers: from a desired load profile at certain places in the network, how to build the "local" controls which allow reaching this profile ;

- Design of new offers for the customers and modeling of their reactions : Communicating meters make it possible to propose different kinds of contracts to customers, compared to the classical ones with a fixed maximum power, and peak hours (at the same hour of the days for everyone or nearly everyone). Complex offers with rates changing during the day, new services (e.g. related to electric vehicles, in home device control, ...) can now be proposed and an important question is how individual customers will choose their contracts, and how they will manage them. Societal considerations as well as economical ones have to be taken into account. The major problem here stands in the fact that the actors proposing these new fares (system administrator and/or professional electricity producers) do not have a clear understanding of individual behaviors towards the whole variety of offers. These behaviors may not follow strategies fully rational as other players of the market. Thus the challenge would be to use approaches of experimental and behavioural economy to test the customers reactions to diverse types of rate offers and to estimate the impact of these offers on the balance of the electric system. Economical studies were realized already (see for instance [ADEME1]). Experiments are already in progress [ADEME2] and need to be complemented with further studies [Sa2016]. This project will be conducted in collaboration with economists of Paris Saclay with a strong expertise in behavioral economics together with specialists of in theoretical and numerical optimal control.

Projects dealing with solving energy related challenges using optimal command, distributed command, synchronisation, robust command ... are welcome.

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