SCHEDULING OF DER FLEXIBILITY IN A MARKET ENVIRONMENT: LESSONS LEARNT FROM THE REFLEXE DEMONSTRATION PROJECT

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ABSTRACT

The Reflexe project aims to examine all aspects of flexibility aggregation and in particular the problem of scheduling flexibility to offer bids to a market. After introducing the overall Reflexe project and the aggregation platform, three scheduling problem formulations are presented. The scheduling results obtained with these formulations are analysed as well as results obtained when applying these schedules to the real-life activation of the flexibilities participating in the project.

INTRODUCTION

The widespread adoption of new communicating device technologies combined with the evolution of market rules have led to the emergence of distributed energy resource (DER) aggregators whose objective is to operate the flexibilities offered by small DERs to provide services to the grid. In France, the market rules allowing demand response to be bid into various markets have undergone significant changes and are expected to continue to evolve as the technology and business cases mature.

In this context, the Reflexe demonstration project [1] brings together 5 industrial and academic partners and aims to investigate the technical and economic feasibility of aggregating small and medium commercial and industrial loads coupled to battery storage systems. The project also examines the impact of coordinated flexibility activation on grid operation and safety, as well as the services that can be delivered by localized, targeted, activations.

To address the objectives of the project, a flexibility management platform was implemented to allow aggregators to build bids that can be submitted to the market. Building flexibility bids is a scheduling problem in which the aim is to define the activation plan of various flexible resources in order to achieve a certain aggregate load or production variation while conforming to market requirements such as minimum bid duration or minimum bid power. To help the trader to perform bid construction, optimization applications were integrated into the flexibility management platform.

After providing an overview of the flexibility management platform and its functionality, the paper presents the optimization models that were developed and tested during the project.

The first part of the modelling effort concentrates on capturing the specificities of different load processes. This includes flexibility forecasting and determination of resource power impact as a function of the resource's activation time, as well as modelling the activation constraints of the resources (e.g. the number of times a resource can be activated in a given day).

The second part of the modelling effort centers on the optimization objective functions that were investigated in the project. The hypotheses surrounding the use of each objective function along with specific constraints are discussed.

The last section of the paper presents experimentation results obtained on the resources participating in the project. These resources include heating and cooling loads from office buildings as well as pumps from industrial locations.

The paper concludes by discussing the lessons learnt during the experimentation on the use of optimization applications to build flexibility bids from a diverse set of resources.

THE REFLEXE AGGREGATION PLATFORM

The objective of the aggregation platform is to automate the management of distributed flexible loads and generators. The platform has three main functions: provide communication to and from the flexible assets, provide decision support tools to help the aggregator offer structured products to the market and orchestrate the activation of the flexible assets so that the cumulated activations fulfil the market or network operator needs.

The aggregation platform is built around several components that interact with each other as well as with different types of users and external systems. The architecture of the platform is presented in Figure 1. The flexible assets, represented as buildings in the illustration,

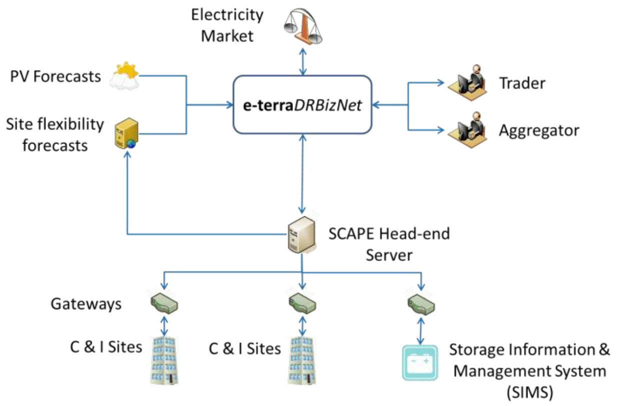

Figure 1: Overview of the Reflexe flexibility aggregation platform

can communicate with flexibility management system through communication gateways installed at the locations. The gateways send and receive messages from a central head-end server that is interfaced with the flexibility management system. The gateways and head-end server were developed by Sagemcom. The gateways can interact with the flexible assets either by interacting with sensors and actuators or by serving as multi-protocol gateways that are interfaced either to building management systems or to the asset control automata. The gateways retrieve load reading from the location load meters and receive activation orders that they translate into actuator instructions or convert to instruction for the control automata. One such "automaton" or control system is the Storage Information and Management System (SIMS) developed by CEA INES to manage a molten-salt Zebra storage system developed in the frame of the project.

The head-end server is interfaced with e-terra*DRBizNet*, Alstom's demand response management system (DRMS). The DRMS serves as the platform's flexibility management solution. The solution is composed of several modules that provide different aggregation functionalities: flexibility forecast management, device data management and flexibility activation, user interfaces offering both technical and commercial aggregator functionality and optimization application to build flexibility dispatch schedules.

The DRMS provides location meter data to external flexibility forecasting systems that use the data along with other external input, such as numerical weather forecasts, to generate forecasts of the location loads and flexibility availabilities. Production forecasts of DER assets, such as photovoltaic (PV) plants, are also provided to the aggregation solution by specialized forecasting systems.

The DRMS functionality can be split into technical aggregation and commercial aggregation functions. The technical aggregation functions include flexibility registration and modelling as well as flexibility activation and monitoring.

The registration process is a contractual as well as a technical process in which the flexibilities of the site are modelled and the contractual conditions under which the flexibilities can be used by the aggregator are defined. The modelling step includes dynamically computing the availability of flexibilities based on their past activation history and the contractual activation limits defined during the enrolment process.

The commercial aggregation functionality focuses primarily on flexibility activation scheduling to provide structured products either to the market or directly to the network operator. In the context of the Reflexe project, the focus is primarily on building bids for energy or balancing markets. The bid building functionality allows the trader to visualize the flexibilities available for the next market gate and to define the parameters of the optimization algorithms that are run to build the bid proposals. Several objectives functions were developed to satisfy different trader preferences and market needs. The objective functions are detailed in the next section.

FLEXIBILITY SCHEDULING

Scheduling flexibility is a two-step process that involves first, modelling and determining the available flexibility, and then determining the flexibility activation schedule that best satisfies a given objective. In this section, we describe the flexibility modelling and forecasting approach that was used in the project and then we present in detail the scheduling optimization models that were tested.

Flexibility modelling and forecasting

Forecasting the amount of flexibility that will be available from a resource at a given time requires modelling the resource and applying forecasting algorithms that can derive the available flexible power values from this model and other explanatory variables such as weather forecasts.

The flexibility management platform allows a detailed model of the resource to be defined. The model includes static parameters as well as flexibility activation rules. The static parameters include parameters such as minimum and maximum flexible power, location maximum and minimum load and a configurable typology of flexible resources. The flexibility activation rule sets are specifically tailored to the resources business requirements. These rules define when and for how long the power consumption or production of a given process can be modified. The activation rules also include constraints on the number of times the flexibility may be dispatched over a period of time. The activation frequencies defined by these constraints are important to limit the attrition rate of resources that may "tire" if their process schedules are modified too often.

The static data and the flexibility availability constraints captured in the model can be queried by the external forecasting algorithms that provide the actual power values. These algorithms use a wide range of forecasting techniques specifically suited to the process being forecast. Although the forecasting process is a major aspect of the aggregation process, it is outside the scope of this paper. For more details on forecasting DER the reader is referred to [2], [3] and references therein.

The forecasting algorithms determine the load or generation at the locations that provide flexibility as well as the impact that will be obtained when the flexibility is dispatched. The impact includes not only the expected variation of load or generation that is sought from the flexibility but also any rebound or snap-back that occurs at the end of flexibility activation.

Flexibility scheduling to derive market bids

The market bid building functionality implemented in the aggregation platform was implemented as a scheduling problem. The aim is to determine the flexibility activation schedule that maximizes some trader defined objective functions. In this section we present three objective functions that were implemented and tested in the frame of the project.

The scheduling problem was modelled as a Mixed Integer Linear Programming problem. The main decision variables are the flexibility activation start times and durations. The problem constraints include flexibility activation constraints (min. and max. number of activations, recovery time between activations, etc.), market constraints (min. bid duration and power, market baselines, etc.) and flexibility availability.

The result of the optimization algorithms is a flexibility dispatch schedule as well as the energy or power amount to be bid into the market. The power or energy amount can take into account the expected baseline that is derived from the load or generation forecasts.

Maximize expected revenue

The main objective function that was developed in the frame of the project aims to maximize the weighted energy that will be provided in the bid. The weights provided by the user are intended to reflect the expected market price for the bid period. In this sense, this objective function maximizes the expected revenue of the bid. Nevertheless, the weights could reflect any other user knowledge or time period preference.

The objective function that is maximized is formulated as:

$$Max\ \{\sum_t \sum_r Power(t,r).EnergyWeight(t).ut\}$$

where:

- $Power(t,r) = Resource(t,r).EventImpact(t,r)$ is the power variation provided by resource *a* for time step *t*, with $Resource(t,r)$ a binary variable indicating if resource *r* is active during time step *t*, and $EventImpact(t,r)$ the amount of power variation that can be provided by resource *r* at time step *t*,
- $EnergyWeight(t)$ is a unit-less weighing factor for time step *t*,
- ut is the length of the optimization time step.

Maximize bid duration

An important bid property is the bid duration. Satisfying specific network needs, in particular local congestion problems, can require having load modifications during several hours. To meet this need, a bid duration maximization problem was implemented. The aim of the problem is to find the activation schedule that can provide a minimum amount of power for the longest period possible, given the available flexible resources. To run this optimization, the user provides the desired bid start time and the minimum power that should be provided during the duration of the bid.

The objective function that is maximized is formulated as:

$$Max\ \{\sum_t BidActive(t)\}$$

where $BidActive(t)$ is a binary variable indicating the bid is active at time *t*. To ensure that the bid will provide a minimum amount of power and that the activation period is continuous, the problem is subject to the following constraints:

$$\sum_r Resource(t,r).EventImpact(t,r) \geq Bid(t).MinPower,$$

Where $Resource(t,r)$ is a binary variable indicating if resource r is active at time t and $MinPower$ is the minimum power that must be provided, and

$$Bid(t) \geq Bid(t+1)\ \ \forall\, t \in T$$

where *T* is the set of time-steps between the bid start time and bid max end time.

Maximize peak power

In other network conditions, the market, especially a balancing mechanism, may require bids that provide high levels of flexibility for relatively short time periods. To cater to this need, a power maximization problem was implemented. The aim of this problem is to find the schedule that maximizes the flexible power provided for at least one of the time steps of the bid period. The user input to this problem is the bid start time and duration as well as the flexible resource portfolio.

The objective function is formulated as

$Max\ \{\sum_r Resource(t,r).EventImpact(t,r)\ ,t \in T\}$.

Using this formulation, the optimization problem can yield dispatch schedules that provide peak powers for single time steps. Specific constraints could be introduced to obtain longer peaks, but this was outside the scope of the present study.

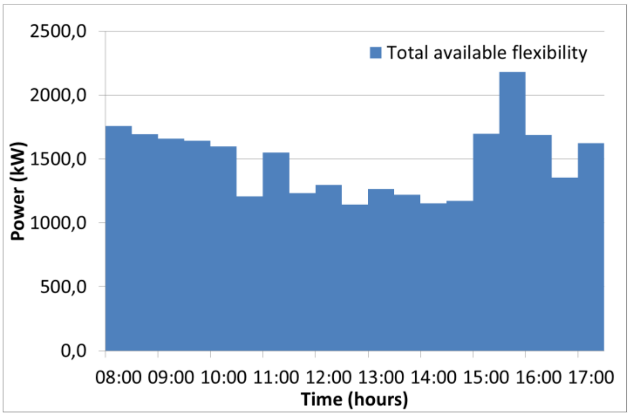

Figure 2: Forecast of the available aggregate flexibility accross the 8 locations.

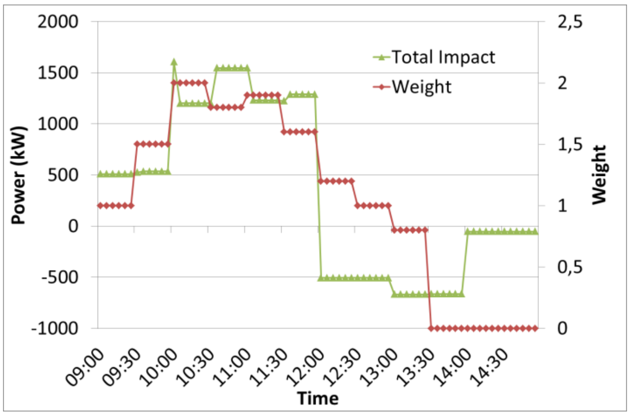

Figure 3: Total impact obtained with the revenue maximization objective function and weight time-series used by the algorithm.

RESULTS

In this section, we present the results of the optimization algorithms based on the flexibility provided by 8 locations participating in the project. The locations comprise 6 office buildings and 2 industrial sites. The flexibility in the office buildings is mainly provided by electric heaters, or heat-pumps, whereas the flexibility of the industrial sites is provided by pumps that are part of the core industrial process of the sites. There are 10 flexible resources in total. The activation times vary from 1 hour to 4 hours for different flexibilities.

The total forecast flexibility between 08:00 and 17:00 for a late winter day is shown in Figure 2. The individual forecasts were used as inputs to the optimization algorithms.

Optimization results

Maximize expected revenue

The expected revenue maximization objective was tested with the aim of creating a bid that starts at 09h00. To maximize the expected revenue, a weight time-series representing, for example, a market price forecast for the period is provided to the optimization engine. The weight time-series is shown in Figure 3.

The dispatch schedule and total dispatch impact are shown in Figure 4. As requested, the bid starts at 09:00 and end at 12:00. Since the weights associated to the first hour of the bid are relatively low, the optimization engine only dispatches resources whose minimum dispatch time is long (3 to 4 hours). When the weights increase at 10:00, all flexibilities are dispatched. In this way the optimizer ensures that most of the flexibility is delivered during the high weight period between 10:00 and 12:00. After 12:00, all the flexibilities have been expended and negative impact appears due to the snapback effect.

By examining the weight curve along with the impact curve (see Figure 3), it is evident that the optimization engine activated the longer running flexibilities in the

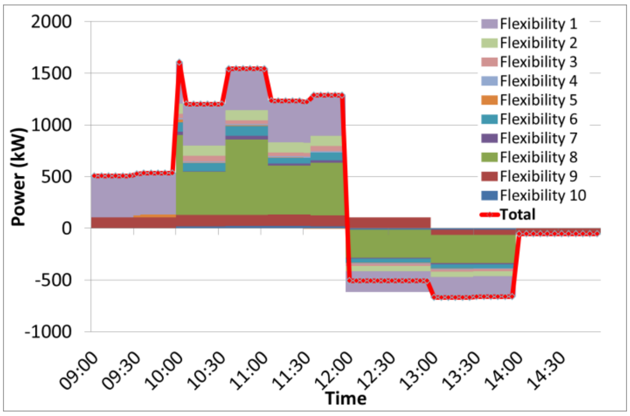

Figure 4: Dispatch schedule and total impact obtained with the expected revenue maximization objective function.

beginning of the bid period to take advantage to the higher weights associated to that period and to avoid the lower flexibility availability period that occurs between 12:00 and 13:00 as shown in Figure 2.

Maximize bid duration

The bid duration maximization objective function was tested with the aim of finding the longest bid that ensures that at least 600 kilowatts of load reduction are provided at all times. The start time for the bid was set at 09:00.

The flexibility dispatch schedule and the total impact that was obtained are shown in Figure 5. The resulting bid duration is 4 hours. To achieve this duration, the optimization engine dispatched two flexibilities for 4 hours. These are specific flexibilities that can be dispatched for long periods. To complement these two "base" flexibilities, additional flexibilities were dispatched, some for 1 hour and some for 2 hours. The optimization algorithm also took care to dispatch more flexibility during the last 2 hours of the event to compensate the snapback that occurs due to some resources being released after their activation. The 600 kW minimum power limit is respected at all times.

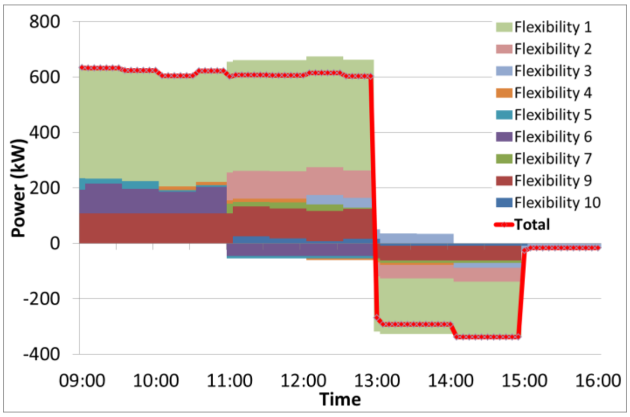

Figure 5: Dispatch schedule and total impact obtained with the bid duration maximization objective function

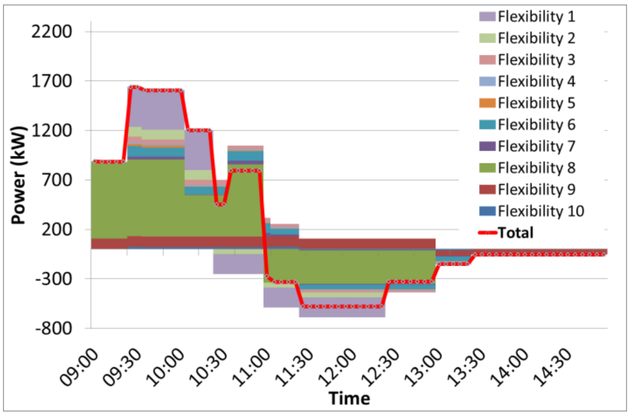

Figure 6: Dispatch schedule and total impact obtained with the peak power maximization objective function

Maximize peak power

The peak power maximization objective function was also tested for a bid start time of 09:00 and duration of 30 minutes. The flexibility dispatch schedule and the total impact are shown in Figure 6.

The total impact reaches a peak value of 1600 kilowatts from 09:20 to 09:30 which is the highest possible impact given the flexibility availabilities. The dispatch schedule may seem odd with most of the flexibility being delivered outside of the bid period, from 09:30 onwards. This is due to the fact that the bid is also submitted to the 600 kilowatt minimum power constraint, so two flexibilities are dispatched to satisfy this constraint during the first 20 minutes of the bid. The peak power being achievable only during the last 10 minutes, the remaining flexibilities are only dispatched at that time. This is done by design in order to reduce and/or postpone the snapback effect to a time well after the end of the bid period. In this example, the snapback occurs 90 minutes after the end of the bid period, and the maximum snapback power is only a third of the maximum bid power.

Activation results

The schedule obtained with the maximize bid power function was tested in a live experimentation session held March 12th 2014. The aggregate load of the 8 buildings considered in the dispatch schedule is shown in Figure 7.

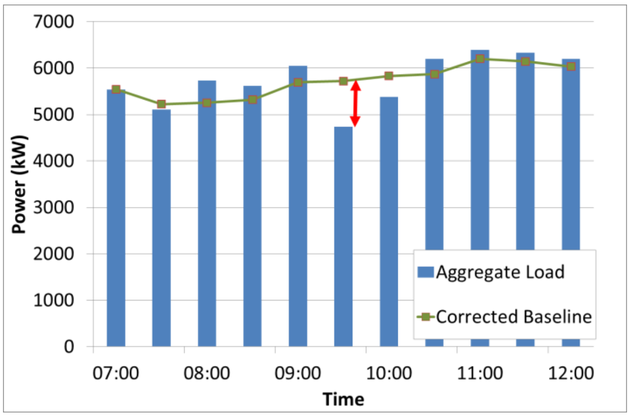

Figure 7: Aggregate load of the 8 commercial and industrial locations and a load estimate based on corrected load forecasts for the locations.

The figure also presents an estimate of the load based on corrected load forecasts for each of the locations. The load reduction with respect to the market baseline was highest during 09:00 to 09:30 period and then decreases for the following time steps. This is compatible with the general shape of the total impact obtained by the optimization but the timing is ahead of schedule. This discrepancy can be explained by the difficulty of accurately predicting the availability and the load of individual flexibilities and locations. However, load reduction is commensurate with that obtained by the optimization, especially since the corrected forecasts seem to underestimate the load for most of the time steps.

CONCLUSIONS

The Reflexe project examined both the technical and economic aspects of flexibility aggregation in a market context. A key part of the work concentrated on modelling the flexible resources and on developing decision support tools that help the aggregator to provide useful flexibility offers to the market.

Several scheduling problems were formulated to build bids suitable for the resolution of different network needs. The results show that solving the non-trivial scheduling problems is feasible and that the real-life implementation of the schedules leads to load variations that are in line with the expected impacts. However accurately forecasting location load and flexibility availability at the individual level remains difficult and leads to significant deviations.

A future development step in the scheduling optimization problem is to more thoroughly assess the impact of forecast uncertainty on the optimization results and to determine the asset aggregation level that provides the best trade-off between forecast accuracy and localized flexibility activation.

ACKNOWLEDGMENTS

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