Analysis on the Profitability of Demand Flexibility on the Swedish Peak Power Reserve Market

Claes Sandels, *Student Member, IEEE*, Mats Hagelberg, and Lars Nordström, *Member, IEEE*

***Abstract*—In this paper, a load reduction Aggregator participating on the Swedish Peak Power Reserve (PPR) market was analyzed. The load reduction was provided by electric heating systems in larger dwellings (e.g., office buildings). Two simulation models were developed to assess the market performance of the Aggregator. From the simulation results it was concluded that the PPR market was not optimal for the proposed Aggregator. Among other things, the market was too inflexible and the profits were just a small subvention of the larger day-ahead electricity purchases. Also, it was concluded that the Aggregator was exposed to several risks by participating on the market, e.g. situations of shortage in available power capacity. A number of countermeasures to mitigate these risks were presented.**

***Index Terms*—Aggregator, Demand Response, Peak Power Reserve Market, Smart Grids, .**

I. Introduction

Society needs electricity function. Even a power outage of a couple hours will stress the society, and imply huge costs for industries, the transport sector, utility companies, commercial entities, etc. [8][12]. Usually, the production and import system in the Nordic power system have no problems to supply the consumers with electricity. But to minimize the probability of power outages during very constrained situations, the Swedish Transmission System Operator (TSO), Svenska Kraftnät (SvK), centrally procures at most 2000 MW of Peak Power Reserves (PPR) for the winter season, annually. The reserves are procured directly with producers, consumers and retailers [8]. The PPR offers fixed capacity payments to the participating players who are willing to offer production (generating electricity) or load reduction (stop consuming electricity). Currently, the TSO is in the process of restructuring the reserves. The biggest alternation, by far, is the willingness to increase the ratio of load reduction. Today, a 75% share of the PPR is constituted by production (i.e. 1500 MW). By 2017, the Swedish policy makers want to fully replace the production (mostly provided by gas turbines and oil fired power plants today) with demand flexibility. In order to realize additional volumes of load reduction to the markets, a lot of focus has been directed to smart grid Demand Side Management (DSM) solutions in the recent years [6]. In essence, DSM concerns the consumers ability to offer load flexibility services to different actors on the power markets. Due to the fact that the average consumer is quite small in size (capacity wise), it is necessary to pool these consumers into bigger chunks. Especially, this is valid from a market point of view, where these often requires volume bids in the range of MWs. Therefore, to be able to fulfill these aforementioned constraints in an efficient way, an actor denoted as the Aggregator is suggested to handle the consumers' loads [3]. The Aggregator is an actor who is centrally controlling the loads of smaller consumers with extensive ICT systems, and offers these load flexibility to various energy markets. Through his market participation, the Aggregator is trying to maximize his profits w.r.t., e.g. regulatory conditions, and customer satisfaction constraints.

Sandels and Nordström are with the Department of Industrial Information and Control Systems, Royal Institute of Technology, Stockholm, Sweden, e-mail: {claess, larsn}@icst.kth.se. Hagelberg is with the Department of Vattenfall Sales and Distribution AB, Solna, Sweden, email: mats.hagelberg@vattenfall.com.

A. Scope of the paper

The main scope of this paper is to present and analyze a load reduction Aggregator service on the Swedish PPR market. The load reduction is provided by actors from the midsize domain (defined as power consumption rates between 63 A and 25 MW). These consumers are most interesting from an aggregation point of view in a middle term scenario, e.g. to 2017. The biggest consumers (heavy industries) are already active on these markets, and the smallest consumers (households) are considered to be plausible in a more long term scenario. The Aggregator service is assessed from an economical and technical point of view. The most important parameters affecting the service, such as market rules, technical constraints of the studied loads, etc., are listed and described. At the end, the service is evaluated in a quantitative simulation model from its market performance. The simulations are based on historical market and temperature data of Sweden.

B. Outline

The remainder of this paper is structured as follows. Section II contrasts the present contribution with some related work in the fields of DSM and capacity markets. In section III, a background to the Swedish PPR market can be found. It is followed, in section IV, by an overall description of the Aggregator service. In section V, the principles and results of the quantitative simulation models are presented. Section VI contains a discussion of the results, and some concluding remarks are given in section VII.

II. Related Work

Analysis of the technical and economic performance of DSM on various capacity markets have been treated in several academic papers. The main results of some the papers are summarized in this section.

In [1], a number of industries from the German context are analyzed w.r.t. their suitability as load balancing resources on their national Tertiart Control Market (TCM). The investigated industry branches are, e.g. chloralkali process, mechanical wood pulp production and electric arc furnace. By inserting data for a future wind generation scenario (i.e., an increased need for control power) into a linear optimization model, the economic and technical performance of the proposed offered industrial DSM bids on the market can be calculated. The authors conclude that activating load DSM from industries can imply cost savings in the range of €0.5 billion between the years 2007 and 2020. The savings are assessed by comparing the costs for conventional peak power production, e.g. gas turbines. The industries are capable of providing 50% of the total German tertiary up regulation need by the year 2020. Further, a study regarding the participation of electric vehicles (EVs) on the U.S. capacity markets is made in [10]. The concept of using the EV batteries for ancillary services is often referred as Vehicle to Grid (V2G). The Aggregator is a critical actor in V2G. Due to the fact that an EV only can contribute with a limited capacity (in the range of kWs), the pooling function will be crucial. The authors show that it can be economically viable for EVs to provide peak power due to its low capital cost, and rather high energy cost (ideal for a capacity market). Moreover, the U.S., peak power resources need to be able to provide power for a period of 3-5 hours, which is technically possible for on-board batteries. Similar V2G studies can be found in [9][2]. Another type of Aggregator is presented in [14]. Here, a cluster of micro-Combine Heat Power units is used to reduce the peak demand of a distribution network (DN) substation in the Netherlands. This is realized through a market based control scheme of software agents (a.k.a. the PowerMatcher concept). Bids are communicated between the agents to optimize the global welfare (i.e., the network operation and the economical remuneration of the users). By using different operation strategies, it is concluded that the PowerMatcher approach can decrease the peak load by 50%, and in the same time fulfill customer satisfaction. The unintelligent fit and forget strategy implied no mitigating effects on the peak demand of the DN, i.e., accentuating the importance of aggregated control in this case.

III. The Swedish Peak Power Reserve market

As stated earlier, the Swedish TSO procures at most 2 GW of reserve capacity directly with producers, big consumers and utilities for each winter season (16th of November to 15th March). The power demand is expected to be high during the winter due to cold weather. The main function of the PPR market is to secure energy volume to the short term markets (day-ahead market and the TCM). The PPR consist of both a production part and a load reduction share. Both of these parts have their own individual procurement processes. In this paper, the focus is on the load reduction part only.

In essence, the PPR market is comprised by two different time frames: (i) the market time period when the procurement process is treated, and (ii) the contract time period where the procured resources are delivering the actual physical service to the TSO. The two market periods are described more in detail in the following sections.

A. Market time period

In the market time period, resource owners (e.g., big industrial consumers with flexible demand) provide load reduction procurement bids to the reserve. These bids are fundamental for the whole procurement process. The TSO evaluates the submitted bids w.r.t. a predefined metrics based on economic and technical conditions. The resource owner starts by specifying his economic claims, i.e., his desired fixed hourly payment and the maximum required up regulation price. Subsequently, the technical segments are identified, i.e. stamina, repetition time, activation time and total power capacity (see Table II for more information). When all the bids are collected by the TSO, he first evaluates them on its economic claims. Thereafter, the claims are penalized if the technical requirements cannot be fulfilled (e.g., not being able to activate the bid within 15 minutes, etc.). The TSO is accepting the bids in an ascending order until their demand is met. In addition to the aforementioned stated requirements, the TSO claim that each bid has one Balance Responsible Party (BRP) (i.e., an actor who is financially responsible for electricity imbalances), and that the load reduction resources is located in the same geographical price area (Sweden is currently split into four price areas).

B. Contract time period

If the resource owner's bid is accepted, he will sign a contract directly with the TSO, which obliges the actor to provide the load reduction service during the following contract time period. Throughout this period, the resource owner has promised the TSO to perform three tasks: (i) submit up regulation bids to Swedish TCM for all the hours the load reduction resources are available, (ii) report to the TSO if the resources are unavailable (e.g., due to a technical failure), and (iii) set their own regulation prices (cannot exceed the max up regulation price that the actor has stated in his procurement bid). Note, the actor is forced to submit bids for all the hours of the winter season (except if the resource is technically unavailable).

IV. The Aggregator load reduction service

Now, when the market rules are defined, the suitable load for the PPR market needs to be acknowledged. In [5], the authors try to assess the potential for offering load reduction from different midsize businesses in Sweden. Table I summarizes the load reduction potential for the different studied industry branches. As can be seen, the total load reduction potential from ordinary industries (i.e., steel, foundry, etc.) is quite limited. The variation in potential for some of branches is due to macro-economic factors. For example, during high business activity, the marginal for performing load reduction is limited due to high demand for the industries produced goods. It is quite obvious that large dwellings (e.g., school and office buildings) have the largest potential for participating on the PPR market (e.g., be able to provide enough volumes, etc.). Here, the consumption is mainly composed by ventilation, heating and lightening. In Sweden, around 30% of all large dwellings are heated by electricity in some way (electric convectors, heat pumps, etc.) [4]. The total annual electric heating demand from this sector is around 6 TWh. This roughly gives an average power consumption of 1 GW throughout the heating season (from September to May in Sweden) in the large dwelling sector. Due to this potential, and in order to delimit the study, it is decided to look upon these sets of loads only. Furthermore, because of the interesting fact that the correlation between low outdoor temperatures (implying heating needs in the dwellings) and an overloaded power system is very high in Sweden, additional incentives to look upon these sets of loads are provided.

TABLE I
THE LOAD REDUCTION POTENTIAL FROM THE STUDIED INDUSTRY BRANCHES

Industry	No. of actors	Type of consumption	Total potential
Steel	10	Heating and melting	0-25 MW
Forging	9	Heating	5 MW
Foundry	200	Melting	25 MW
Chemistry	220	Electric motors	10 - 20 MW
Food industry	220	Freeze storage	30 - 40 MW
Large dwellings	Many	Ventilation, heating	$>$ 200 MW

A. *The market participation*

Before the market time period, the Aggregator needs to find and contract service providers (the large dwelling actors, e.g. offices) to his pool of load reduction resources. The Aggregator has to attract these service providers with incentives, such as money, for their participation. When the service provider has agreed to enter the aggregation, the Aggregator must be provided the parameter values concerning the buildings thermodynamical characteristics. Evidently, the Aggregator requires these values to determine the technical bid parameters which are necessary for the TSOs procurement process (see section III-A). Subsequently, the actor's bid is either accepted or rejected by the TSO. If the bid is accepted, the Aggregator will deliver the actual load reduction service throughout the winter season in the contract time frame. Here, three different market windows have to be accounted for, i.e. the day-ahead market (viz. Elspot), the TCM, and the post settlement. At Elspot, the Aggregator needs to buy electricity on an hourly basis for the upcoming 24 hours. The purchases must correspond to a volume which is sufficient to maintain a reference indoor temperature for a given forecasted outdoor temperature. Notably, the outdoor temperature is the main variable who affects the energy consumption in the studied set of loads. Moreover, after the market operator has reviewed all the sell and buy bids, a price cross will be obtained for each hour. Based on these prices, the Aggregator can prepare his up regulation bids to the TCM. Afterward, during the real time operation, the TSO is determining its need for control power based on the unbalance of the power system. If there is a large demand for up regulation power during a specific hour (e.g., due to a power plant failure), the TSO will start to activate the commercial up regulation bids. If these bids are insufficient to meet the demand (i.e., the frequency is still at a low level), the TSO will be forced to activate the PPR. Note, due to the fact that heavy industries (e.g., wood paper pulp plants) are usually frequent bidders on this market, and they require a very high activation cost [1], we can assume that the activation of a PPR will require a very high up regulation price (in the range of €500 /MWh). So, by acknowledging the up regulation market prices, an activation price signal of the PPR can be appreciated. If the Aggregators bid is activated, he will provide volume to the power system by decreasing the electric heating consumption of his service providers. This will go on for 1-2 hours, and will indeed reduce the indoor temperatures of the buildings (however, it cannot exceed the services provider's minimum indoor temperature constraint). In order to get the temperature back to its reference temperature, the heater needs to be operated at a higher set point in the coming hours. In other words, by reducing the consumption at one point of time, the consumption will increase at a later time. Of course, this will cause energy imbalances for the BRP w.r.t. to his market commitments on the day-ahead market. These imbalance need to be settled at the post market, where the BRP is punished through a one price system for the imbalances [11]. This market procedure (i.e. acting on three different market windows) needs to be executed for all the 120 days of the PPR season. Finally, after the contract time frame has ended, the Aggregator needs to evaluate his performance throughout the period. Questions, such as profitability, technical performance and efficiency, need to be addressed and answered. This is done to enhance the knowledge and experience to calibrate improved bids for the upcoming seasons.

V. THE SIMULATION MODELS

Two simulation models are needed to analyze the Aggregator load reduction service. The first model, denoted as the seasonal model determines the technical bid parameters in the procurement process (i.e. the market time frame). These values are subsequently inserted to the daily simulation model (the second model). This model assesses the historic profitability of an Aggregator on the market, i.e. the simulations are based on deterministic data. In the following subsections, more elaborate functioning and principles of these two simulation models are presented.

A. *The seasonal model*

Obviously, on the PPR market, the procurement bid is a very important element. Therefore, an individual model for assigning values on the bid parameters is crucial. The first segment that needs to be investigated is the timing and frequency of the activation of the reserves. As discussed and visualized in section IV-A, the PPR market is assumed to be activated at events of extreme up regulation prices. By analyzing market data from [13], it can be concluded that the frequency of these price levels is very low (around 1- 2 times a year). Also, a majority of the activations are realized in the morning hours, i.e. the morning peaks between 7 and

TABLE II
THE PARAMETERS OF THE AGGREGATOR SERVICE

Parameter	Values	Description
α_p	$\alpha_p \geq 5$ MW	The total capacity stated in the procurement bid.
α_{act}	$\alpha_{act} < \frac{1}{4}$ h	The activation time stated in the procurement bid.
α_{sta}	$\alpha_{sta} \geq 2$ h	The stamina stated in the procurement bid.
α_{rep}	$\alpha_{rep} < 6$ h	The repetition time stated in the procurement bid.
β_{fix}	$\beta_{fix} >$ €0 /MW/h	The fixed capacity payment stated in the procurement bid.
β_{var}	$\beta_{var} \leq$ €5000 /MWh	The maximum up regulation price stated in the procurement bid.
K	10	The number of service providers in the aggregation. Each service provider is labeled *i*.
P_i^{max}	2 MW	Installed power of the electric heater for service provider *i*.
τ_i	100 h	The time constant of the building for service provider *i*.
Λ_i	0.04 MW/K	The isolation factor of the building for service provider *i*.
$T^{out}(t)$	Historic data	Outdoor temperatures for the last 50 years in the Stockholm region, for each hour *t*. Collected from [15].
T_i^{ref}	21^{o}C	The reference indoor temperature for service provider *i*.
T_i^{min}	18^{o}C	The minimum allowed indoor temperature for service provider *i*.
$p_{reg}(t)$	Historic data	Hourly Swedish up regulation prices for the PPR season for 2004-2012. Collected from [13].
$p_{spot}(t)$	Historic data	Hourly Swedish spot prices for the PPR season for 2004-2012. Collected from [13].

9 a.m. Due to this fact, it is reasonable for a load reduction Aggregator to have a stamina of two hours (the minimum requirement of the TSO) to cover the most probable need of the market. In order to determine the rest of the bid parameters, assumptions and models of the service providers buildings have to be defined. Therefore, reasonable values for the insulation, time constant, and installed heating capacity for these buildings need to be determined. It is decided to fixate these values based on the characteristics of an office complex in Stockholm, Sweden [7]. The thermodynamical equations defining the heating process in buildings can be found in [16]. Further, to keep the simulation computation complexity down, an aggregation of ten service providers is assumed. Also, the buildings have identical parameter settings (see Table II for more details). The model can easily handle additional service providers with dissimilar properties. However, the main purpose with the model is to see the overall trend of providing bids from such loads. The aforementioned assumptions and parameter settings are believed to be sufficient. Moreover, by fixating the building parameters and the stamina of the bid, and allowing the outdoor temperature varying according to historical data in Sweden for the past 50 years, a diagram of the rest of the bid parameters can be generated. This diagram is displayed in Fig. 1. As seen, the daily mean outdoor temperature, for the winter season, follows a normal distribution with a mean of ca. -1.5^{o}C. Further, there is a low probability for very cold temperatures (e.g., -20^{o}C), and the same is valid for warm temperatures (e.g. +10^{o}C). Logically, when the outdoor temperatures decreases (moving in the right direction of the x-axis), the electric heaters need to work harder to be able to maintain the indoor temperature. The available capacity, therefore, has a negative linear relationship w.r.t. the outdoor temperature. The next parameter that needs to be examined is the repetition time, i.e. how fast the resources can deliver power again after an activation. This parameter is described by a negative exponential curve. In other words, if the heaters are cut off at cold temperatures, the repetition time will be very high. For example, if the heaters are turned of for two hours at -20^{o}C, it will take the system around seven hours to be back at its initial state. Clearly, by analyzing the variability of the outdoor temperature, the technical system of heaters will have different capabilities over time. Therefore, the Aggregator needs to acknowledge the risk his willing to take for not meeting his obligations to the TSO, such as lack of capacity. By drawing a line which indicates a confidence interval for the outdoor temperature variable, the risk of a shortage in capacity can be assessed in a quantitative way. Then, the Aggregator can be quite certain from a historical note, that the capacity his offering from his service providers, he will be able to meet his obligations at any given time with a 95% probability. Some discussion can be made however, if it is feasible to base future bids on what has been happening in the past (the weather can alternate heavily over years). Furthermore, as observed in the same figure, it is cold at the times of activation, stating that the PPR demands correlate quite well with low outdoor temperatures. However, note, the PPR market is insurance for the TSO, and requires it for the whole market period to ensure the safety of the power system operation. Therefore, we have to assume that the bid must have a high availability. By choosing a 5% risk for not fulfilling the bid, the parameter vales can be deduced.

B. The daily model

So, now when the procurement process is defined, the performance of the bid in the contract time period can be simulated and assessed. The principles of the simulation model follow the daily market logic expressed in section IV-A. The PPR periods of 2007 to 2012 are simulated in this paper. Note, in the model, it is assumed that the Aggregators obligations on the day-ahead market, corresponds exactly with the real time conditions for each hour. In other words, no forecasts errors in outdoor temperatures are expected.

In Fig. 2, an example day of extreme up regulation prices is shown. The subplot at the bottom right depicts the up regulation price and the spot price for each hour. At 7 a.m., the up regulation price spikes, indicating that the TSO needs to activate the PPR. Therefore, the Aggregator receives a signal to turn off his service providers heaters. By performing this action, the indoor temperature will decrease (as can be seen in the upper right plot). Thereby, Aggregator is providing balancing volume to the power system (displayed in the lower left subplot).The capacity bid is locked at 6 MW as derived from

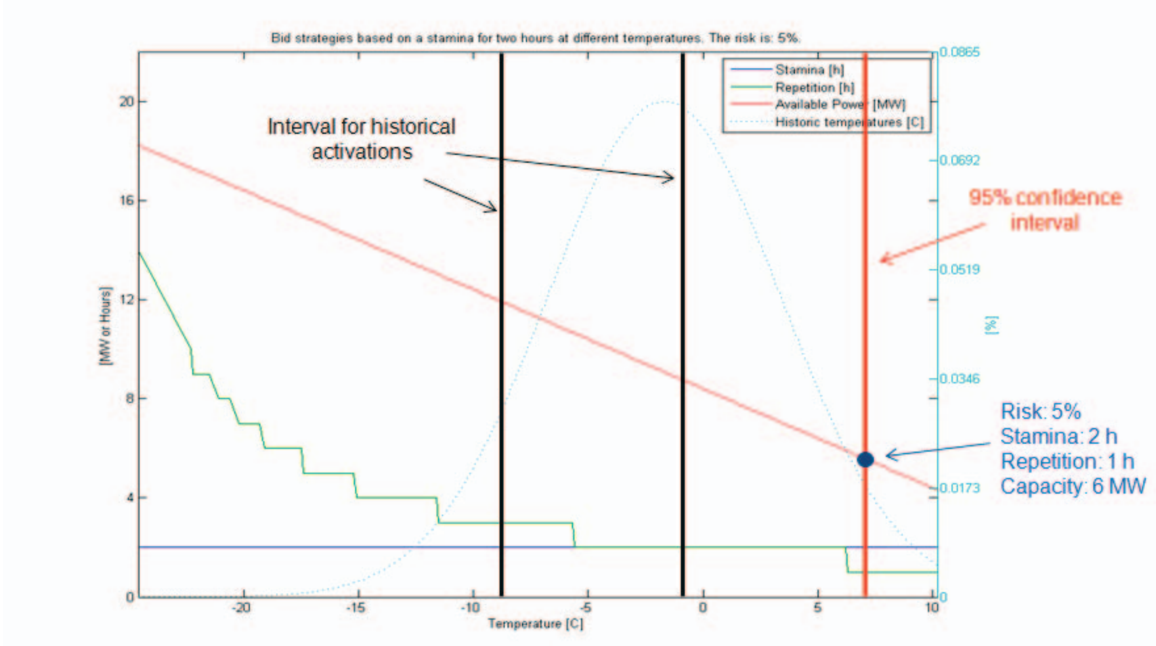

Fig. 1. The procurement bid parameters w.r.t. historical outdoor temperatures

the seasonal procurement model, and, therefore, provided. However, during this specific time, the outdoor temperature is ca. -18^{o}C, suggesting that the available volume is much higher than 6 MW (indicated by the blue curve). Evidently, money opportunity is lost here because less volume is provided to the market than what actually available. Furthermore, as can be seen in the same plot, when the temperature returns to its set point, the imbalance volume caused by the payback effect is quite significant (difference between the light blue curve and the blue curve). Finally, the bid parameters stamina and repetition time is visualized in the upper right plot. As noticed, in this example, the Aggregator has no problem to fulfill these bid requirements.

TABLE III
SIMULATION RESULTS FOR FIVE PPR SEASONS

Season [year]	07/08	08/09	09/10	10/11	11/12
Fixed income [k€]	32.3	34.2	31.9	34.8	31.6
Variable income [k€]	14.2	12.4	21.1	24.7	0
Imbalance cost [k€]	3.2	3.1	14.8	15.1	0
Earned profit [k€]	43.3	43.5	38.2	44.4	31.6
Day-ahead purchases [M€]	9	11	20	19	9
Mean outdoor temp. [°C]	2	-0.5	-3.6	-3.9	0.2
Availability [%]	93	98	93	99	92
Activation ratio [%]	0.14	0.07	0.49	0.31	0

Table III summarizes the simulation results for the five PPR seasons. Among other things, the expected profit (fixed income + variable income imbalance cost), and the availability of the Aggregators bid are listed. The profit is very small in comparison to the purchases on the day-ahead market. To be able to provide the service at all (i.e., put bids on the TCM), the Aggregator needs to go via the day-ahead market. Therefore, the participation of a load Aggregator on the PPR market must be seen as a way to subsidies the costs the actor has on the day-ahead market. Furthermore, the bid shows a high availability (from 92-99%). This is however an expected result from the seasonal model, which calibrated the bid according to a 95% probability of fulfilling the bid at any given point in time. Of course, during cold winters, as for the season 2010/2011, the bid shows a very high availability. The variable income (payment from activating the up regulation bid) is quite low in comparison to the fixed income when the imbalance cost for the BRP is taken into account. This means that the payback effect is a parameter which needs to be acknowledged and handled by the Aggregator. Note, no costs for the technology enabling the Aggregator service (e.g., the communication, measurement, and control equipment) are included in the model. Therefore, when the costs are included, the profitability is likely to decrease for the Aggregator.

VI. DISCUSSION

The results from the simulations suggest that the current PPR market is very inflexible, which is not favorable for the studied Aggregator service. The procurement bid, for instance, must be submitted to the TSO almost six months in advance. Evidently, the weather for the upcoming winter season is impossible to forecast. Therefore, the Aggregator needs to have an approach which estimates the uncertainties of having a shortage in available capacity. To hedge against this risk, the Aggregator is required to put capacity bids which are quite modest. The actual need of the PPR market, however, is normally correlated with low outdoor temperatures. Nevertheless, the TSO requires a 24 hour standby mode of the load reduction resources throughout the period. This implies that the difference between the lowest and highest available capacity throughout the period will be significant. Thereby, a recommendation for the TSO is to remove this criterion, and replace it with a bidding system that respects outcome values for variables, such as the outdoor temperatures. Furthermore,

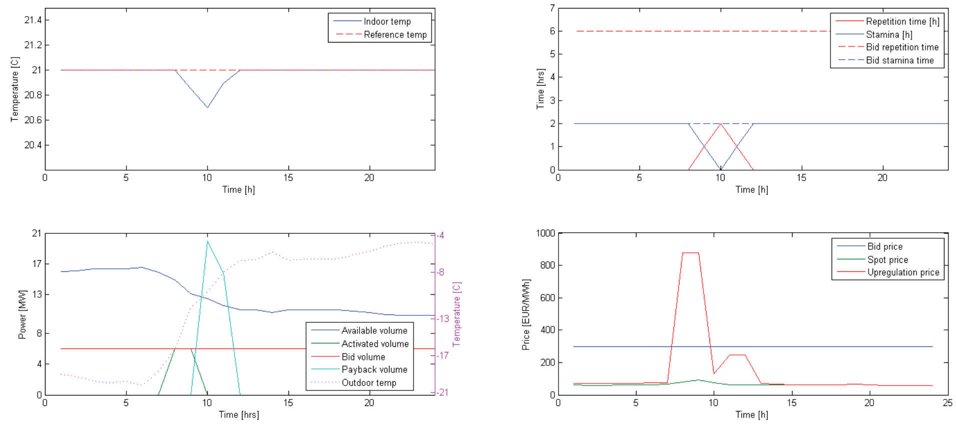

Fig. 2. An example day (February 25th of 2011) of when the bid gets activated on the PPR market

to participate on the PPR, the Aggregator is required to act on the other electricity markets as well (e.g. the day-ahead market). The actual profit on the PPR is therefore dependent on the prices of these markets. As observed in Table III, the expected profits are between 31.6 and 44.4 k€ for the different periods. However, to obtain these profits, purchases on the day-ahead market are required. And, for the season 2009/2010 these are 20 M€ in total. Consequently, the PPR market must be seen as a way to receive subventions on the electricity bills of the service providers (e.g., a subvention of about 5% for the 2007/2008 season is received). Nevertheless, the cost reduction may be higher if the service provider changes the source of the heating to, e.g., if plausible, a remote heating system. Further cost benefit analysis regarding these alternatives must be conducted to be able to draw any conclusions which is out of scope for this paper. This is, of course, an obvious risk for the Aggregator. If the service providers stop using electricity as an energy carrier, no demand flexibility will be available for the PPR (i.e., market opportunities are lost). Last but not the least, the profitability of the Aggregator is dependent on the up regulation price levels, and the difference of these and the spot prices, i.e. the price margin between the two markets. In general, these margins are rather low in Sweden because hydropower can provide regulation power both easily and cheaply. Evidently, there is no guarantee that the up regulation prices will peak during the season. To compensate this risk, the Aggregator can require a higher fixed capacity payment by the TSO. However, this action will affect the probability for the procurement bid of being accepted.

VII. Conclusion

In this paper we have studied a load reduction Aggregator on the Swedish PPR market. It was decided that the load reduction supposed to be provided by electric heaters from large dwellings. By constructing two simulation models, the economic and technical performance of the aggregation on the market could be assessed. From the simulation results it was concluded that the todays PPR market was not optimal for this type of Aggregator. Among other things, the market is inflexible (the procurement bid is submitted a long time in advance), and the profits were just a small subvention of day-ahead purchase. Also, it was concluded that the Aggregator was exposed to several risks, e.g. situations of shortage in capacity. Some countermeasures to mitigate these risks were presented. Note, no costs for enabling the Aggregator service was assessed in the paper (e.g., for the ICT infrastructure). Therefore, the expected profitability of an Aggregator was likely to decrease.

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