Pricing methods for users’ reaction in the energy flexibility management

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Abstract. This paper presents a basis of the energy flexibility market and rules how all market actors can participate on it. It also describes and summarises financial results of a business case elaborated during project implementation. The e-balance system/platform itself is a result of the European (FP7) collaborative project: E-balance (2013-2017): Balancing the energy production and consumption in energy efficient smart neighbourhoods.

1. Introduction

Due to the growing share of variable renewable generation in Europe, energy flexibility is becoming more and more important[3,5,7]. Renewables in the electricity grid create a greater need for flexibility management in the system. The flexibility could be used by suppliers to optimize their portfolio, by grid operators to delay or avoid network reinforcement and manage congestion management, and by the Transmission System Operator (TSO) for balancing and regulating management purposes by reserve services and markets.

The way in which energy is being used nowadays is changing drastically[6]. Generally, an increase in the number of renewable energy sources, a change in the demand profile, energy generation to meet individuals’ own needs, and striving to increase self-sufficiency, lead to the need for energy flexibility management and dedicated application/platform for the active demand response (ADR) management.

We can say that a new type of service and market have emerged, i.e. the flexibility market. All market players play certain roles on it. Industrial, commercial and residential prosumers/consumers are very important on this market and have an important role to play. In some countries, such as Germany and Austria, consumers have begun to provide flexibility to be used for provisions of services, such as tertiary reserves. Energy storage providers have a potential of their hydro storages, which however currently are not fully used in many countries. Potentially, they are also good providers for flexibility.

Residential prosumers could play a major role in providing flexibility referred to as an active demand response[4,5], however they need an aggregation service between them and the market. This service can be provided by a new player, i.e. the aggregator, an entity responsible for combining all small portions of their flexibility into a bigger pool, and offer it on the market on behalf of such small prosumers. This idea provides a background for the e-balance platform, which is the main result of the e-balance project (EU FP7). This platform has been tested in demo sites in Bronsbergen (the Netherlands)[11].
The e-balance system is a communication platform with a set of tools necessary to operate it, which was developed under this project. This system supports management of energy exchange among small prosumers operating in local, smart neighborhoods. The aggregation service allows them to earn real money for their active response (shifting the use of energy or consumption decrease in selected hours) to the aggregator’s energy profile proposition. The new business model has been theoretically worked out[1,2,9,10]. Its economic results for the proposed pricing model are now analysed under a simulation and sensitivity analysis.

2. Prosumers on the flexibility market
The key question is how the prosumer can ‘earn money’ for being active, i.e. for delivering his/her flexibility to the market. Which benefits can be offered to the market due to the increased flexibility of demand. In other words: which advantages will be offered to the power system by this new flexibility resource and how the prosumers will benefit from the flexibility that they will be able to offer.

The ADR is an active behavior of the user/prosumer who responds to such signals from the grid that will encourage him/her either to reduce or increase energy consumption at a given time or increase/decrease energy generation from his/her generation sources as required. To provide this capacity, systems such as the e-balance platform are able to collaborate with appliances and equipment of the prosumer and support him/her in making decisions for some financial reward.

Under one option[10], the prosumer will have access to real prices operating on the power market. These prices reflect the ongoing supply-demand balance to facilitate a response to suspend energy consumption (using the user’s own energy produced) or ‘move’ the consumption to other ‘cheaper’ hours. This mechanism is referred to as the price-based mechanism (implicit demand response). It has been implemented in some countries for industrial and commercial segments.

The incentive–based or explicit demand response represents another option. The prosumer will receive an additional incentive for delivering a specific flexibility volume at a specific time following a request from the aggregator. This solution is more suitable for energy balancing and system adequacy as the flexibility can be tailored to the market needs.

This type of collaboration between the consumer and the market requires establishing a new functionality or a new entity on the market, and the aggregator’s function offers this potential. The aggregator’s task will be to offer an aggregation service, i.e. to aggregate all flexibility sources based on the time and volume parameters in one bid to offer it on the market.

The aggregator can be a so-called independent entity (independent model), where it will act as an independent entity, i.e. it will be an independent market stakeholder positioned between the distribution operator and the supplier. The aggregators usually hold a dedicated (balancing responsible party) BRP, or are such entities themselves (at the Medium Voltage (MV) level), to sell the aggregated flexibility on the market.

Based on another approach, the aggregator can act as a separate functionality of the supplier (integrated model). It will closely collaborate with energy suppliers to optimize their purchase portfolios. In such circumstances, the BRP relevant to the supplier will represent his/her energy purchase bids precisely matched to the market based on the day ahead and the current day prices.

The third type is called the semi off model of integration and is dedicated for microgrids and private or small DSOs/communities.

It should be emphasized that depending on the way in which a specific aggregator operates and whether it is separated from the other entities operating on the market, different flexibility products will be provided as a result of the aggregation service used in the e-balance system. In the e-balance project we have called it as follows:
**Direct Energy Flexibility (DEF)** – a flex product dedicated to the balancing market and auxiliary services. Requests for an aggregation can be initiated due to the lack of balance and appropriate bids resulting from the balancing market and reserves market.

**Indirect Energy Flexibility (IEF)** – a flex product dedicated to optimize portfolio of a retailer/supplier and provide a precise schedule of energy purchases by them on the day ahead/intraday market (DAM/IDM) or for the purpose of the DSO, and efficient management of the grid operations flexibility.

### 3. The models of aggregation considered during the project

Which structure can the flexibility market have, where is the space for the aggregators, and according to which rules can they provide their services? This is a basic question which requires our research into the available literature and guidelines contained in the EU[3-5,7] documents and in other projects (e.g. USEF project).

| Category | Integrated model | Semi-off model | Independent model |
|----------|-----------------|----------------|-------------------|
| Goal     | Support energy supply management and portfolio optimization | Support congestion management and local balancing | Energy exchange management and energy flexibility management |
| Most interested and profitable party (in order) | Supplier, Aggregator, Prosumers, DSO | DSO, Aggregator, Prosumers | Aggregator, Prosumers |
| Conflict of interests | none | Aggregator - Suppliers | DSO- Aggregator and Aggregator – Supplier. The suppliers have no reason to participate in the aggregator’s target |
| Aggregator’s activity | Aggregator also supports the management congestion, but sometimes the DSO has opposite targets than the supplier | Aggregator supports mainly the DSO, the supplier doesn’t have the interest to act actively on behalf of the aggregator | Aggregator is fully independent, he/she can serve all parties (DSO, supplier, TSO). The flexibility market should be fully developed |
| Risk management | Typical operational and commercial risk is incurred by the supplier and his BRP, only a new functionality is added | Operational risk is on the DSO side, but commercial risk both on the aggregator’s and supplier’s side | Full risk is incurred by the aggregator and the BRP |
| Balance responsible party (BRP) | No need for a new entity | No need for a new entity/depending on a specific solution it is possible to establish a new BRP | A new BRP for flexibility products delivery is needed, and should be incentivized/payed by the aggregator for its service |
| Flexibility products | Mainly an indirect flex product will be delivered | Mainly an indirect flex product will be delivered | Both flex products (IEF/DEF) will be delivered |

*Source: based on results of the e-balance project implementation.*
Due to the characteristics of the hierarchical model of the e-balance platform implementation [11], a hierarchical system of aggregation in the grid has been planned. The aggregators will be excluded from the Low Voltage (LV) grid at the lowest level, while at the MV level, a group of aggregators of a lower level and prosumers connected to the MV grid will operate.

Within this structure of connections it is important which model of collaboration of the aggregator with the other market players, i.e. with the DSO, suppliers and relevant Balancing Responsible Party (BRP), will be adopted.

Based on the results of an analysis of the proposed business model concept, the following models of the aggregator’s role implementation have been proposed during the e-balance project: Integrated model, Semi-off model, and Independent model [10].

Not all of these models are possible to implement. Table 1 presents a comparison of features of these models. These features indicate complexity, unrealistic possibility, or even a high risk of failure in terms of implementation. Therefore, for further analysis only one, i.e. the integrated model, has been selected as the most beneficial for all involved stakeholders, in which the risk level is shared among all the parties.

The model of integration proposed for the aggregator’s role, which we have named the integrated model, has been selected for further consideration and simulation under business cases. The remaining models are described in detail in the project documentation [10].

In this model the prosumer endorses a contract with an energy supplier, which will regulate both the purchase and the sale of energy to the grid. Additionally an amendment concerning the service to aggregate product flexibility will be endorsed with these prosumers that will have e-balance platform appliance installed. Pursuant to this contract the prosumer shall undertake to participate actively in the local balancing and aggregation processes, and for this kind of involvement, he/she will earn appropriate profits, i.e. gain incentives. Additionally, the prosumers will undertake to pay the cost of subscription as well as the cost of aggregation service (a fee payable to the aggregator).

In terms of their operations, the aggregators shall depend on the supplier, i.e. they will provide the services to the suppliers. Due to this arrangement they will not bear any operational risk nor be responsible for any shortage of flexibility supply (imbalance). This risk shall be borne by the supplying entity. The supplier shall optimize its forecasts of energy purchase and sale per each hour of the day (per every 15 minutes), and thanks to the aggregation service, it will be able to provide better matched contracts of energy purchase on the day-ahead market and on the intra-day market. The aggregators which will be mainly adopting this system will ensure delivery of the DEF product on the markets. Also in the case of balancing bids and the market of reserves, the active BRP entity will be able to notify of the need to respond to the bids of the market of reserves.

On behalf of the supplier, the applicable BRP will provide the DEF product without its explicit identification (in the units of not using power). The operator responsible for distribution will hold an extended contract endorsed with the supplier, which will additionally lay down services of the aggregator. Thanks to these additional provisions, the operators will be able to have an operational cooperation, including the function of aggregation, to facilitate grid flexibility management.

Due to the needs of management of flexibility and quality of flows in the DSO level grid, it will be possible to ‘send enquiries’ (steering signals) to the aggregator and to the prosumers. The enquiries will concern a specific reaction/response depending on the grid condition, therefore the provided DEF product (prosumer’s response – reaction/ response) will be a product ‘for’ the operator. This model should indicate the way according to which the operator will be able to encourage/reward the prosumers for the product generated upon its request (e.g. reduced fixed charges for the distribution service, or other incentives).

This model does not explicitly support management of flexibility and flexibility provision. Its ultimate goal is to support management of optimization of bids of the energy purchase and sale on the market by the supplier and the assigned applicable BRP. This will prevent speculations of the prosumers and support the system of voluntary participation of the prosumers on the flexibility market. The prosumer will respond only when he/she wishes to respond. Obviously we assume that
the prosumer will use a specific time of use tariff (TOU) concerning purchase of energy from the grid based on his/her response to the price – the prosumer will know the prices thus will be able to adjust to this profile of consumption that offers maximum benefits. Thanks to this the prosumer will behave in a sound manner and the e-balance system will support this process by automating its actions (scenarios of behaviors).

All incentives for the prosumer included in this model are generated at the level of operations of the supplier that will calculate remuneration for the BRP, the aggregator and the prosumers.

4. The research questions
The following research questions have been posed for the purpose of a further analysis of the service aggregation and products offered:

- It is flexible demand product profitable in current situation on energy markets, and offer fair gains for all parties involved in these activities.
- How to define and calculate parameters of the settlements between the parties.

To answer these questions theoretical considerations concerning the integration models and the role of the aggregator on the market have been conducted:

- An integrated model of aggregation has been proposed for further analysis and considerations as a business case for both Poland and Netherlands.
- Price mechanisms and business models among the key market players have been proposed.
- Simulations and data-focused estimates have been performed and relevant results obtained for several developed business cases.

4.1. Pricing the prosumers for shifting the loads – TOU activity

In this section we will focus on the DR actions analysis, based on load shifting. Let's assume that these activities are valued dynamically, on a day-ahead basis. The aggregator analyses the effects of DR activities, and determines the amount of compensation for users dynamically for each next day.

TOU actions are in most cases used to cost optimization of the procurement of energy. Therefore, in this study, we will analyse the pricing methods and business results of demand elasticity for this goal. In our study we will assume that the day is divided into 24 time intervals \( h = 1, ..., 24 \), corresponding to the trading hours on the energy market. Of course, if you need to divide the day into shorter periods, it is easy to generalize the presented results. In our simulations studies of pricing methods we assume also flat retail price of the energy for final users \( p_s \).

The pricing of flexible demand response product requires taking into account settlements on the three levels hierarchy supplier-aggregator-user. We assume that settlements between supplier and aggregator are based on share \( \lambda \), \( 0 \leq \lambda \leq 1 \), of the aggregator in the profits from demand response actions. We will not discuss here the topic of determination of the aggregator’s share \( \lambda \). In our simulations it was selected as optimal value to maximize the profit from demand response action for supplier. But it may be chosen also by negotiation.

The settlements between aggregator and each users are based on the price incentives \( p = (p_1, ..., p_{24}) \), for each hour, paid by the aggregator to the user for each unit of energy consumed during the hour. These payments are intended to shape the desired load curve. The pricing method must take into account this property. Incentives \( p_h \) should be higher for the hours in which the aggregator wants to induce the user to increase demand, lower or even zero, for the hours when the aggregator wants to achieve reduction of the load. In addition, of course, the aggregator incentives must be nonnegative and lower than the retail price the energy \( p_s \).

Denote further by \( d(p) = (d_1(p), ..., d_{24}(p)) \) total load of all aggregated prosumers for each hour, given incentives daily profile \( p \). The aggregator, as a rational entity pursuing its own gain, will strive to maximize its daily profit, i.e., on a given day, it should set such price incentives \( p \) on the one hand to increase its revenue resulting from the effects of DR activities, and on the other hand reduce the
expenditure on those goals. So, the incentives \( p \) can be determined solving the following optimization problem:

\[
\max_p \lambda \Delta c(d(p)) - \sum_{h=1}^{24} p_h d_h(p)
\]

\[p_h \geq 0, q_{ih}(p) \geq 0 \quad (1)\]

where \( \Delta c(d(p)) \) denotes change in costs of procurement of the energy for a given prosumers demand \( d(p) \) (gain from the demand response), and \( q_{ih}(p) \) demand of the individual prosumer \( i \), for the hour \( h \), in response to the incentives \( p \) (it means, off course, that \( d_h(p) = \sum q_{ih}(p) \)).

Solution of the problem (1) requires the development of the model of prosumer demand reaction for the incentives \( q_{ih}(p) = (q_{i01}(p), \ldots, q_{i24}(p)) \) in confrontation to some baseline demand of this prosumer \( q_{i0} = (q_{i01}, \ldots, q_{i24}) \), without any of the demand response actions. In our simulations we obtained this model as solution of the maximization of prosumer revenues from demand response in opposition to the disutility function, denoting dissatisfaction of the prosumer from the necessity of shifting the load. It can be shown ([14]), that for quadratic user disutility function the user’s reaction model is given by:

\[
q_{ih}(p) = \frac{1}{2v_i}(p - p_h) + q_{i0} \quad (2)
\]

The parameter \( v_i \geq 0 \), defines the prosumer’s inelasticity and can be selected for the differentiation of user groups whose load is determined primarily by the various types of home appliances. Its low value indicates a slight lack of satisfaction when changing the demand pattern (e.g. in case of washing machines). The high value of \( v_i \) indicates a more sensitive receiver (e.g. using electricity for cooking) [14]. In practical applications of e-balance platform, after collecting the appropriate volume of data, the prosumer’s reaction model should be obtained rather empirically.

We will now present the simulation studies effects of the discussed above load shifting pricing model and the shaping of the daily demand profile of users, used to optimization of the energy purchase costs on the stock market (Warsaw TGE and EPEX SPOT Power NL day-ahead markets). Keep in mind that the obtained results have potential character, and once the system is implemented, will require verification using the real data, baseline load profiles of the users and their actual response to the incentives used.

In the first simulation study, we used real energy prices on the Polish day-ahead market (Warsaw TGE), from the whole year 2016. Also, all estimates of profits of the involved entities, from the use of load shifting to optimize purchases, will be calculated over the same period.

As the first topic let us consider the problem of finding the optimal share of the aggregator in DR gains (coefficient \( \lambda \)). The profits of the energy supplier are initially rising, as the share of the aggregator \( \lambda \) increases, thereby also increases the level of incentives for the users. Once a certain maximum value has been reached, the costs of the DR activities begin to outweigh the revenue generated and the profit starts to decline. The aggregate income of the aggregator at which the energy supplier achieves maximum profits depends on the elasticity of the prosumers. For users with lower elasticity, it is profitable for the supplier to increase the amount of money given to the aggregator so that he can use stronger incentives for the users. The obtained in simulations values of the optimal for the supplier share of the aggregator \( \lambda \) are shown in Table 2.

**Table 2.** Aggregator’s share (\( \lambda \)) in DR revenues, giving maximum supplier profits for different levels of customer elasticity \( v_i \).

| \( v_i \) | 0.0025 | 0.005 | 0.01 | 0.015 | 0.02 |
|---|---|---|---|---|---|
| \( \lambda \) | 0.45 | 0.45 | 0.5 | 0.55 | 0.6 |
In the remainder of the current section we will refer to the data related to the optimal value for the energy supplier of the aggregator’s share $\lambda$, in DR revenues.

In Table 3, are shown simulations of supplier, aggregator and user profits in 2016, depending on the level of elasticity of the users and assuming a customer number 5000. It follows from them, that DR's actions in analyzed business case are profitable for all parties involved. However, the level of profits is highly dependent on the elasticity of the users, their tendency to adjust their load in response to proposed incentives.

With high flexibility of the customers in the analyzed business case, the estimated total supplier's profits would exceed one million zlotys, the user total incentives would be at the level of one hundred and tens of zlotys, and the total gains of aggregator would approach half a million zlotys. In case of weak response of the users, the benefits of individual participants may be several times lower. Hence, it is important to point out the necessity of ongoing pursuit of promotional and marketing activities, encouraging recipients to take part in shaping their loads, and reinforcing the flexibility of their response.

The presented analysis of the benefits concerns a group of 5000 users participating in DR activities. This does not, however, change the generality of considerations, since the profits of all parties are linear on the number of users.

In the second simulation study the energy prices data from Dutch day-ahead market (EPEX SPOT Power NL) were used. Results of simulation studies are similar to these obtained for Polish stock energy market, and are presented in Table 4. It contains results for the four characteristic levels of users’ elasticity. Also in Dutch case it is clearly visible, that the elasticity of the users can bring significant benefits to all three actors involved in DR activities. With high elasticity of the customers in the analyzed business case, for relatively small users pool size assumed in simulations, the
estimated total supplier’s profits would exceed hundred thousand Euro, the user total incentives would be at the level of twenty five Euro, and the total gains of aggregator would approach fifty thousand Euro. In case of weak response of the users, the benefits of individual participants may be several times lower.

4.2. Pricing the prosumers for load reduction (curtailment) at request

Let’s now consider the case of using demand reduction at request as a flexible product in the bidding processes on the balancing market or ancillary services market. In this case we are rather not be interested in building a maximum demand reduction from the point of view of profits in energy trading, but rather to obtain a reduction at a certain level of \( Y \), and to determine the costs (total or unit costs) associated with achieving this goal. This information will be further used to build the bid.

In this case, the aggregator will seek the price incentive \( p \) (price for the unit of load reduction) that must be used to build demand reduction at level \( Y \). So the goal of the aggregator is to find such an incentive value \( p \geq 0 \), that total change in demand of all aggregated prosumers \( \Delta d(p) = \sum \Delta q_i(p) \) for this incentive will be equal \( Y \):

\[
\Delta d(p) = Y 
\]

(3)

or alternatively:

\[
\min_p f(Y - \Delta d(p))
\]

\[
p \geq 0
\]

(4)

where \( f \) is a certain penalty function, determined by the cost of too low (or too excessive) demand reduction.

The user model of the reduction \( \Delta q_i(p) \) in our simulations was obtained from maximization of prosumer gains:

\[
\Delta q_i(p) = \frac{1}{2v_i} p
\]

(5)

where parameter \( v_i \geq 0 \), like in previous section defines the prosumer’s inelasticity.

We had performed simulation study of this pricing method in business problem related to creating a flexible demand product for balancing or a various ancillary services auctions. We will not determine the final financial effect of this type of activity, it depends on how the prepared bid is used. Instead, we will look at the relationship between reduction costs resulted from the method discussed in the current section (the sum of user incentives) and the reduction volume in the created bid, at different levels of customer elasticity.

Again as in previous cases, the simulations will be conducted under assumption that the size of the pool of prosumers involved in DR activities is 5 000. Also, this does not change the generality of our considerations, as the obtained results depend on the number of users in a linear way. For the analysis of the current business case, cost simulations for the bandwidth demand reduction bid creation, ranging from 1 to 5 MW, in bands of 1 MW, were carried. The maximum reduction of 5 MW demand, with a pool of 5000 customers, requires an average reduction of 1 KW from each of them, which can be difficult to achieve and seems a reasonable pre-limitation for such activities. Creating higher volume reduction bids will likely require the increase of the number of users participating in DR activities.

In Figures 1 and 2, graphs of unit and total costs of the load reduction for individual power bands with different elasticity of the users are presented. As we can see the results of the simulation show that the creation of demand reduction in the quantities under consideration is possible at acceptable price levels. The unit costs that form the basis for the subsequent bid prices for individual bands, grow linearly along with the reduction, which in turn results in a quadratic increase in the total costs of the
bid. Again, there should be noted a clear link between the costs of reduction and the level of response elasticity of the users.

Figure 1. Unit costs of users’ incentives per megawatt demand reduction for different levels of customer elasticity (\(v_i\)) at a pool of 5,000 users.

Figure 2. Total costs of users incentives per megawatt demand reduction for different levels of customer elasticity (\(v_i\)) at a pool of 5,000 users.

5. Conclusions and further works

The discussed methods of pricing business activities in the field of flexible customer demand management for “integrated model” of aggregation, have yielded the correct results, allowing the proper pricing of the undertaken actions. The prices obtained were fair, allowing for the benefits of the e-balance platform by all the players involved.

Simulation studies have also shown that the discussed pricing methods also enable the creation of a flexible demand product used in bidding processes on the ancillary services markets. They allow to set reasonable prices for demand reduction bids that are optimal for its size.

Obtained results in all cases show a strong dependence of the effects of business activities on the elasticity of the users, i.e. their willingness to respond to incentives used by the aggregator. This allows us to conclude that a necessary factor for the proper functioning of the presented mechanisms and for achieving high income is a constant need for promotional activities, both in terms of activating users and increasing their pool size.

Please note that the proper process of pricing of flexible demand and their financial settlements for individual parties, requires constant use of the e-balance platform functions, related to collecting information about the behavior of users and prediction of their loads. There are at least two basic components that are critical to the functioning of the system:

- Rigorous collecting of the baseline load data of users and forecasting of their underlying demand, to determine the basis from which the reduction is measured, both for pricing purposes and for later settlements.
- Monitoring user response to incentives used, forecasting changes in their flexibility, or even adjusting the type of response to the actual behaviour of users.

Another open issue is the problem of market power of individual parties, especially regarding the settlements between the aggregator and the energy supplier, trading a flexible product. In our research, we adopted a pricing system based on a monopolistic model, in which the supplier determines the
aggregator's share by maximizing its own profits. In further studies, we plan to analyze the negotiation pricing model, taking into account the greater market power of the aggregator.

Finally, it should be mentioned that this paper deals only with general financial aspects of demand response activity on functional level. There is also a number of important technical and organizational topics associated with specific market regulations and requiring further studies, like e.g.:

- How to estimate the demand and consequently the price/bid on the flexibility market for the offered flexibility bandwidth secured by the BRP that will represent a group of aggregators or an individual aggregator?
- How to remunerate the prosumers, the aggregator, the supplier/BRP and the system owner/provider of e-balance services?
- What will happen in the situation of an imbalance when the prosumers promised to provide more flexibility than they have really provided? Who will be responsible for such situation?

Acknowledgments
This work has been partially founded by the e-balance project (Project Number: 609132), under the European Commission’s 7th Framework Programme (FP7-SMARTCITIES-2013) and the grant of the Ministry of Science and Higher Education: 3009/7.PR/13/2014/2; (PL). http://www.e-balance-project.eu.

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