Development of market design with focus on demand side participation

Niels Christian Bang, Felicia Fock, and Mikael Togeby (Ea Energy Analyses)

Abstract

In the current Nordic electricity market, large electricity end-users can adjust their electricity consumption in relation to the day-ahead market. The process is straightforward as the end-user can act on published prices and no communication is needed. The retailer simply buys electricity on behalf of all its customers based on historical data. This uncomplicated process deals with price dependent consumption with a minimum of communication and administration.

In other markets, e.g. the market for regulating power, demand is in practice excluded. Various rules – that have been developed for traditional power plants – hinder electricity consumers in participating. Electricity demand can be a superior resource for regulating power as the demand can be controlled in seconds and is particularly efficient for short term adjustments. Furthermore, the price variations are higher in the regulating power market than in the day-ahead market, so the economic incentive for adjusting the demand is also higher.

This paper will describe the current market for regulating power, the structure of the demand for regulating power, and the obstacles for demand to participate. The FlexPower project involves the design and simulation of a new market for regulating power. One of the core aspects focuses on how a new regulating power market, which can work as a supplement to the existing market, can be designed.

The principle idea is to expose end-users to five-minute prices and that it is voluntary for them to react. As such, the end-user does not have to send in plans or submit bids. In this way the system is easy to use and unbureaucratic for the end-users. This is expected to be essential for the potential end-users. The balance responsible is expected to predict the change in demand based on historical data – as is done today in the spot market.

1 Introduction

With the introduction of more intermittent power generation in the Nordic power system it is anticipated that there will be an increased demand for regulating power. In the Danish system regulating power is currently provided primarily by central power plants, in combination with import/export to Norway and Sweden where there is a high share of hydro power. As a greater portion of the electricity provided comes from wind power, less will come from these central plants, thus further increasing the need for regulating power from new sources.

One way of supplying regulating power capacity from new resources is to activate the demand side. This could be resources such as industrial or commercial electricity demand, as well as household electricity demand such as heat pumps, direct electric heating, electrical vehicles and other types of demand that can be controlled with little or no consequences to the end-users. Electricity consumption for heating or air conditioning could for example be converted into thermal energy (heat or cold) during one hour, to provide the service (desired temperature) at another hour; thus involving storage of heat or cold and the shifting of electricity demand from one time to another.

The FlexPower project involves the design and simulation of a new market for regulating power that can work as a supplement to the existing market. The project is supported by Energinet.dk and involves the following partners: Ea Energy Analysis (coordinator), DTU-Technical University of Denmark, Enfor, Actua, Eurisco, EC Power, SEAS-NVE and Nordjysk Elhandel.

This paper will describe one of the core aspects of this project, namely the market design. More information about the project can be found at: www.flexpower.dk.

1.1 Current market for regulating power

The Transmission System Operator (TSO) is responsible for the overall security of supply and to ensure a well-functioning electricity market by maintaining the electrical balance in the power system, and by developing market rules. Electricity production and consumption always has to be in balance, and 45 minutes before the operating hour the task of balancing the two is left to Energinet.dk. It maintains this balance via the regulating power market, and other markets for automatic reserves.

In the hour of operation, Energinet.dk utilises several types of reserves to ensure the stability of the system. The reserves can be grouped into automatic and manual reserves. Generally speaking, the system criteria are initially managed by the automatic reserves, which are activated in accordance with frequency deviations or deviation in the actual compared with the planed exchange with neighbouring areas. These reserves are expensive and have limited capacity.

To anticipate excessive use of automatic reserves and in order to re-establish their availability, regulating power is utilised. Regulating power is a manual reserve and is defined as increased or decreased generation that can be fully activated within 15 minutes. Regulating power can also be demand that is increased or decreased. Activation can start at any time and the duration can vary.

	Generation	Demand
Up-regulation	More	Less
Down-regulation	Less	More

Table 1: Definition of up and down regulation

In the Nordic countries there is a common regulating power market managed by the TSOs with a common merit order bidding list. The balance responsibles (for load or production) make bids consisting of amount (MW) and price (DKK/MWh). All bids for delivering regulating power are collected in the common Nordic NOIS-list and are sorted in a list with increasing prices for up-regulation (above spot price), and decreasing prices for down-regulation (below spot price). These bids can be submitted, adjusted, or removed until 45 minutes before the operation hour. In Denmark the minimum bid size is 10 MW, and the maximum is 50 MW. Taking into consideration the potential congestions in the transmission system, the TSO manages the activation of the cheapest regulating power. An example of the NOIS-list is displayed below in Figure 1.

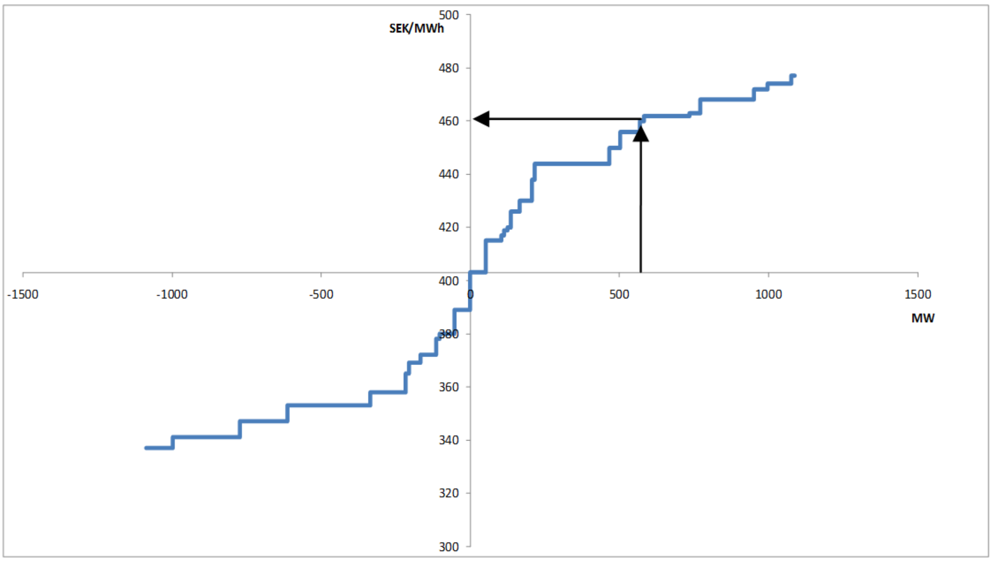

Figure 1: Example of the NOIS list, from 17.6.2009, CET 07-08. 583 MW of up regulating power was activated, corresponding to a price of 460 SEK/MWh (Data provided by SvK).

After the day of operation the costs of activating regulating power are passed on to the balance responsible agents whom were responsible for the imbalances. Both production and demand can cause imbalances, but until now mainly production can benefit from acting in the regulating power market. The only Danish examples for demand used as regulating power are electric boilers. In 2009, 54 MW of electric boilers participated in the regulating power market with down regulation, a figure that is expected to increase to 300 MW in 2011.

1.2 Limitations of current regulating market

The current design has some drawbacks that if removed could make the regulating power market more efficient in the future. For example, small-scale demands and small-scale generations are, in practice, excluded from the market. Current requirements that hamper demand side involvement in the regulating power market include:

- A 10 MW minimum bid size
- A plan for the controllable load: The plan must be followed and must exist with 5-minutes values
- Demand must be re-established after activation: In some cases this may be difficult if special staff are needed for re-establishing demand, for example some forms of industrial production (Johansson, 2008).
- Real-time measuring of regulation units: Real-time metering is relevant in relation to consumers in the +10 MW class. However, for small consumers, the cost of such a requirement is prohibitive.
- The bidding process in itself requires several active actions. First a bid must be made, then if chosen the supplier notified, and finally the actual regulation must

occur. This is an undesirably bureaucratic process for smaller resources and a simpler design might attract more participants (Veen et al, 2009).

1.3 Aspects of current regulating power market

A central reason behind involving demand response into the regulating market as opposed to in the spot market is that there is a greater need for it, and therefore more potential profit to be made in the regulating market. One way of investigating this hypothesis is to review the historic differences between hourly regulating power and spot prices. For the years 2005 through to the start of August 2010, the absolute hourly difference between the regulating power price and spot price was calculated.

Figure 2 below displays duration curves of the hourly differences between the spot price and regulating power prices for DK1 (West) and DK2 (East) from Jan 1st, 2005 till August 10th of 2010. The average spot price over the period was 309 DKK/MWh in DK1 and 325 DKK/MWh in DK2.

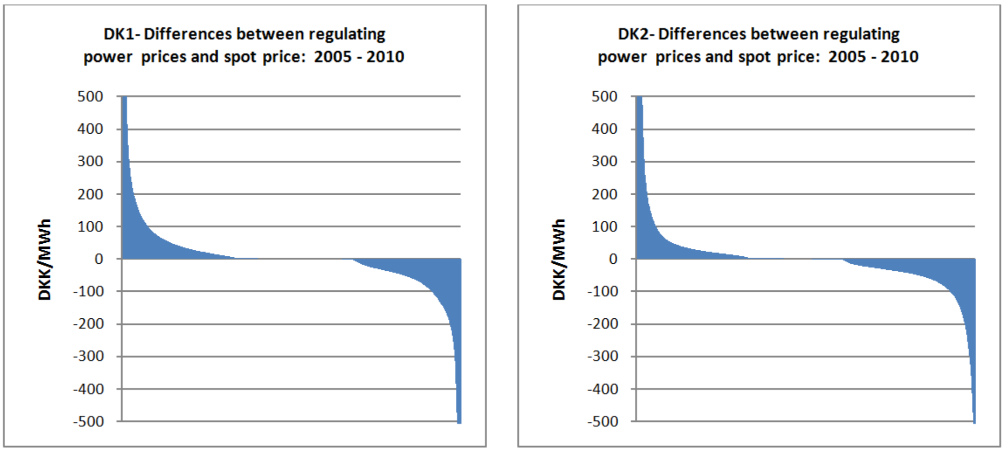

Figure 2: Historical differences between spot and regulating power prices in DK1 (West) and DK2 (East) from Jan 1st 2005 till August 10th 2010. For ease of illustration the vertical axis has been limited to +/- 500 DKK/MWh, thus excluding a total of roughly 2% of hours in both of the graphs (see Table 2 below)

As can be seen from Figure 2 and Table 2, for both DK1 and DK2, on average the absolute difference between the spot price and regulating power price has been 66 DKK/MWh. However, there is a great deal of variation in the data, as more than 1/3 of the hours had an absolute total difference of less than 10 DKK/MWh, and roughly 1/7 of the hours had an absolute value greater than 100 DKK/MWh.

	DK 1	DK 2
Average spot price (DKK/MWh)	309	325
Hours with differences greater than 500 DKK/MWh	1.5%	1.1%
Hours with differences less than - 500 DKK/MWh	0.5%	1.0%
Hours with a difference greater than 100 DKK/MWh	7.5%	5.6%
Hours with a difference less than - 100 DKK/MWh	8.5%	7.3%
Hours with a difference less than +/- 1 DKK/MWh	32.6%	24.8%
Maximum difference (DKK/MWh)	7,034	14,712
Minimum difference (DKK/MWh)	- 6,566	- 10,136
Average absolute difference (DKK/MWh)	65.5	65.5

Table 2: Historical differences between spot and regulating power prices in DK1 (West) and DK2 (East) from Jan 1st 2005 till August 10th 2010.

Lastly, it is interesting to note that the tips at either end of the duration curves are very steep, and as such while rare in number, those hours with large variations (e.g. vary low prices) can be very interesting for the end-user.

1.4 Future Development

While the minimum bid size in Denmark is currently 10 MW, Enegerginet.dk can activate part of a bid after agreement with the bidder (Nordel, 2008). This could be particularly applicable in FlexPower as it is well suited to reacting on smaller bid sizes.

In Nordel's 'Harmonisation of Balance Regulation in the Nordic Countries' report, Nordel also opened the door to smaller bid sizes in the future, something that the report indicates would help to promote demand-side bidding (Nordel, 2008).

Another topic that the report touched on was the potential for other types of bids being included in the NOIS lists. Faster responding bids for example could be earmarked on the bid list and utilised as special regulation. This is something that was also mentioned in an Energinet.dk (2010) report, where it also referenced to potentially incorporating 'self regulating' into the regulating power market, thus signalling a willingness to incorporate other forms of regulating power such as those proposed in FlexPower.

2 Design of a new market

The objective of FlexPower is to develop a real time market for regulating power that will attract a large number of small-scale resources (demand and distributed energy resources) to the regulating power market. This can be created by maintaining the current markets as the basis for planning for the system operation, and then expanding the current regulating power market with a new system: *A one-way price-signal for regulating power*. The fundamental idea behind the FlexPower concept is that participating in the market should be voluntary, simple, and straightforward for the end-user.

The primary market design questions to be answered are thus: How could a system with a one-way price be designed, and how can the FlexPower mechanism be integrated into the present electricity market, including the market for regulating power?

2.1 Co-existence with current market

The current regulating power market will exist and function as today, and as a starting point larger power plants will still contribute with the main volume in the regulating power market. When the system operator selects a bid from the sorted NOIS list, the marginal price is the most expensive bid selected. The fundamental idea behind FlexPower is that if a load balance responsible (LBR) is activated in the regulating power market to deliver regulating power by increasing/decreasing the consumption from end-users, the marginal price (or a form of it) could then be sent out as a one-way price signal to end-users participating in FlexPower. Every five minutes this signal could be sent out to all participants with controllable loads that decide to subscribe to FlexPower.

Response to the price signal will be voluntary and the price signal acts as the final settlement. Based on past experience the balance responsible creates a curve (see below).

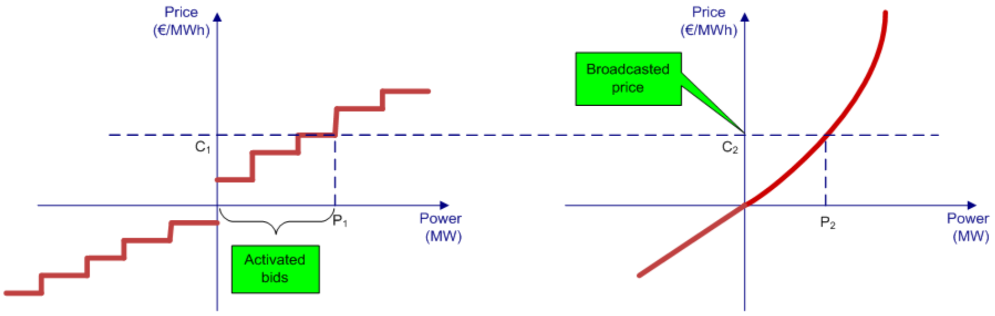

Figure 3: The current market for regulating power (left) and the suggested one-way price signal sent to the end-user from the LBR/retailer (right.)

This curve could be used as a new type of bid, or general bids in the form of stepwise bids representing a price and a volume could be used. The latter will most likely be easier to introduce, largely due to the fact that these kinds of bids are well known in the existing market. However, under the current market structure these bids must have a minimum bid size of 10 MW. In a FlexPower proposal comprised of many small end-users, if the minimum bid size restriction was loosened, to for example 1 MW, this could make a small stepped bidding process more feasible.

The end-users that could be interested in participating in this system would have some electricity uses that are suitable for control. This could be electricity in relation to heating (e.g. heat pumps, direct electric heating, or industrial processes), cooling (e.g. industrial cooling, retail, air condition etc.), pumping (e.g. a water treatment plant) or charging of electric vehicles. In addition, micro generators could also be active in this market. This could be small CHP-units or other controllable generation.

2.2 Simple for end-user

In FlexPower no reservation price will be paid to the end-users. Although a reservation price may be attractive for some demand side actors, this would complicate FlexPower unnecessarily, and it is not expected to be essential.

Another aspect that makes it simple for the end user is that they are not required to bid in to the market. The LBR does this on their behalf, and the FlexPower subscribers respond to price signals from the LBR. This price signal will be sent out every 5 minutes, regardless whether regulating power has been activated or not. When regulating power has not been activated, it is assumed that the LBR will simply send out the spot price.

It is anticipated that the reaction from the end-users will be highly predictable, since there will be many end-users, and the majority will have automatic control systems. The aggregated reaction is expected to be influenced by e.g. time of day, out-door temperature and spot prices. This hypothesis will be tested in the FlexPower project.

2.3 Time plan and interplay between actors

The figure below is one way of presenting the interplay between the actors in FlexPower. In principle the description of the “loop” can start at any of the points, but since FlexPower is focused on introducing more end-users to the regulating power market, the following description will start with the 5 minute metered data at the end-user.

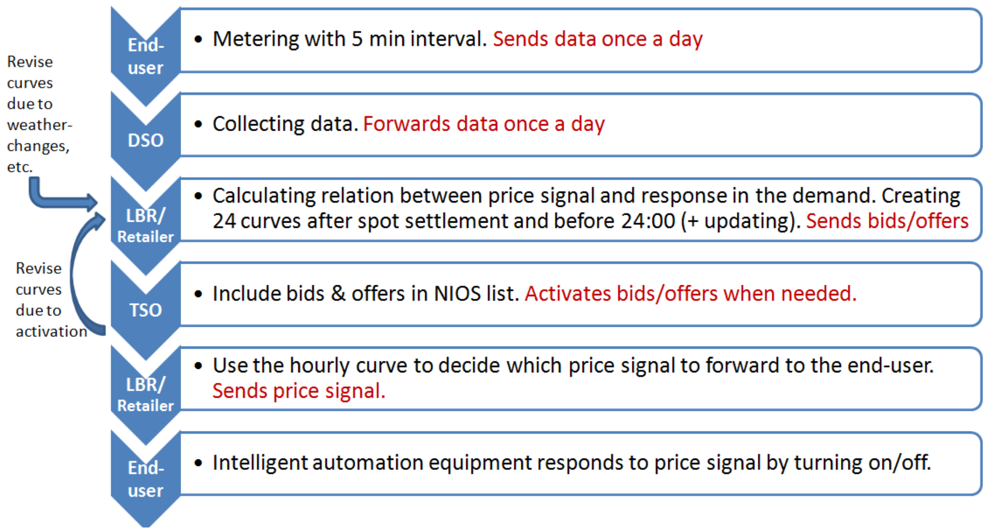

Figure 4: The FlexPower process, starting with the end-user’s data being measured and sent daily.

For all customers participating in FlexPower, the end-user’s consumption is read in an interval meter each 5 minutes. Once a day these data are sent to the distribution system operator (DSO), whom forwards this data to the LBR. To improve the LBRs price signal computation process, it is envisioned that a small percentage of the end-users will send unverified 5 minute data directly back to the LBR, thus providing the LBR with immediate feedback, and allowing them to continually update their price signals accordingly.

Based on historical data for consumption, the LBR forms a prognosis for each hour of the next day (hourly values), and this is used to bid on the spot market (before 12:00). The LBR also creates 'relation curves' for each hour showing the relation between the power available for up or down regulation and the price. These curves are based on how the end-users have traditionally responded to changes in prices signals, and are created according to historical 5-minute consumption data. Currently, 5 minute consumption data are not available, however with the FlexPower project requiring the installation or upgrading of meters to make them capable of measuring at 5 minute intervals, this dataset will grow quickly over time.

After the spot market settlement for the following day has been released around 13:00, the LBR incorporates this information into its continuous value curve calculation. These expected demand side reactions to the regulating power price signals (the hourly curves) are converted into a series of stepwise bids and offers for each hour. The LBR sends the series of bids and offers for each hour to the TSO to participate in the regulating power market. The bids and offers are sent on equal terms with other bids (and offers) to the regulating power market, with the FlexPower concept envisioning the possible exception that the LBR may be allowed to send bids and offers with smaller minimum bid sizes than the 10 MW. One hour before each operating hour, an updated final version of these stepwise bids and offers for regulating power (based on the curves) are sent to the TSO. The bids and offers could resemble that depicted in Figure 5 below.

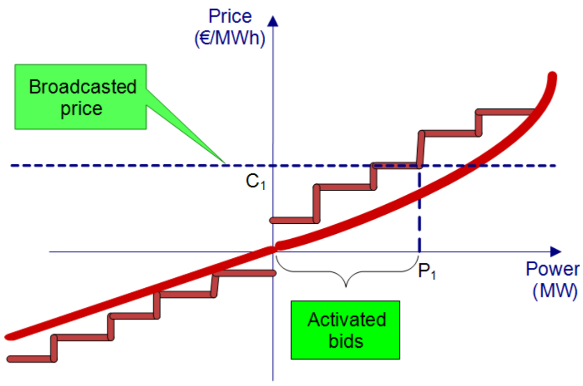

Figure 5:The bids and offers are shown as steps in the graph. The area between the steps and the graphs represents the profit to the balance responsible. It could be argued that the steps will be closer to the graph, or even crossing the graph. This depends on the risk willingness from the balance responsible.

The bids and offers for delivering up or down regulation are collected in the common Nordic NOIS-list. All bids and offers from load balance responsible and generation balance responsible actors are sorted in the list with increasing prices for up-regulation (above spot price), and decreasing prices for down-regulation (below spot price).

When an imbalance in the system occurs, bids or offers from the list are activated by the transmission system operator (TSO) and the corresponding LBR is contacted. Based on the activation price and the relation curves, the LBR then sends a price signal to the end-users participating in the FlexPower system.

At the FlexPower end-user, equipment with automation will include the new price in their internal optimisation. Since each end-user does not make a plan for the consumption and therefore can't detect the change in consumption, the price signal is valid for the total consumption, and not only the change. The equipment will therefore include the new price in their internal optimisation, not only for the up/down regulation, but for the total consumption, and if it is profitable, change the status (on/off) or load of the various electric devices.

The local computer may compute a prognosis for the regulating power price to reduce risk. If electricity demand can for example only can be disconnected for a limited time, the expected future price is important.

2.4 Financial Process

For the FlexPower end-user, the real-time price signal sent by the LBR is the settlement price. At times when there is no need for regulating power, the price sent by the LBR will simply be the spot price. Assuming the FlexPower end-user has a meter capable of measuring in 5 minute intervals, for each 5 minute period the end-user simply pays the LBR product of the amount of electricity used and the real-time price signal.

Another way of viewing the financial process is to look at a timeline of interactions from the perspective of the LBR.

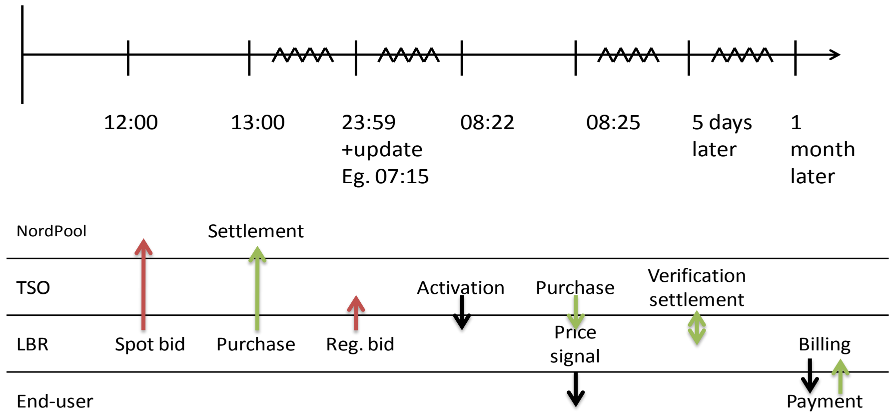

Figure 6: Timeline of events under the FlexPower setup

Assuming that the LBR purchases its electricity on the Nord Pool spot market, the first financial transaction for the LBR occurs when the next day's initial operating plan is finalised at 13:00. At this point in time the LBR knows how much electricity it has purchased, and at what price.

Assuming the LBR does not take part in any bilateral or Elbas transactions, the next financial transaction for the LBR occurs when one of its regulating power bids are activated by the TSO. The activated LBR bid quantity is multiplied by the highest (lowest) price of activated up (down) regulation in that hour, and this value is the amount paid by the TSO to the LBR for up (down) regulation.

After the fact, it's determined whether the amount of electricity that the LBR purchased in the spot market (plus electricity possibly purchased/sold in the regulating power market) equalled the amount of actual demand from its end-users.

3 Risks and opportunities

There exist a number of risks and opportunities that must be orientated, primarily where the LBR is concerned.

3.1 Risks

The first potential risk occurs because there can be a deviation in settlement between the TSO and the LBR compared to the settlement between the LBR and the end-users. In FlexPower there is only one price (per each five minute interval) for the end-user and there is no distinction between planned and actual demand, since it would be very administrative and complicated for the end-user to produce a plan for consumption (and thereby be able to distinguish between the plan and a deviation from the plan/actual demand). Put another way, seen from an end-user perspective, all demand is priced equally within the 5 minutes interval. This however creates a risk for the balance responsible as the price signal that the LBR sends out to its FlexPower customers applies to their entire power usage, but the LBR has bought some of this in the spot market, and some in the regulating power market. Therefore the LBR incurs a risk that they will have paid more in the spot market for power they sell to their customers during hours with down regulation. However, in hours with activated up regulation, the LBR can sell electricity purchased in the spot market for a higher price.

The second major risk that must be orientated is that the duration of an activation will affect the price. The longer the activation lasts, the more expensive it will be to deliver the same volume of regulating power. This can be explained by the fact that most of the regulating power delivered by consumers is not a change in total energy consumption, but merely displacement in time. This means that for instance during up regulation, where the cheapest possibilities of reducing (postponing) demand are activated first, then after a while some of this demand will need to start consuming, regardless of the price.

This could for example be a cooling unit that at first is cheap to shut off if the temperature is somewhere in the middle of the accepted interval. After a while the temperature will rise, and when the max temperature is reached the cooling unit will start regardless of price signal. At this point another, and more expensive, unit must be activated to maintain the same volume of regulation. This can be illustrated in the following graph as the curve becoming steeper and steeper as the duration of the regulation lasts.

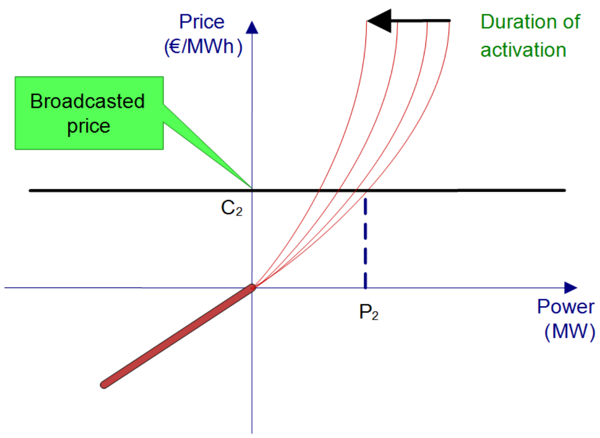

Figure 7: Affect of duration of a regulation on the price signal required to maintain an up regulation

3.2 Opportunities

On the other hand, there are also opportunities for the LBR to profit. For example, under the current rules, the hourly settlement price for regulating power is the highest (lowest) bid price for up (down) regulation activated in the hour, and this settlement price is first made public after the hour. However, under the FlexPower proposal as outlined above, the price signal is determined based on the value of the last activated bid, and as such may very well be lower (higher) than the up (down) regulating settlement price for the total hour. The result for the LBR is a potential profit as it will receive the higher regulating price from energinet.dk, but pass on the lower price via the real time price signal to the FlexPower customers.

Another opportunity for the LBR is the different possibilities with respect to the ramping up/down of the regulating power. In the case of down regulation, the LBR can send out price signals motivating the FlexPower consumers to ramp up consumption instantaneously, gradually, or at the last possible moment, as long as the activated bid is 100% effective after 15 minutes and the ramp rate is in accordance with TSO guidelines.

This gives the LBR an opportunity to adjust how fast the end-users should react to an activation with respect to what's most profitable for the LBR.

The above opportunities and risks must all be considered by the LBR when designing its business model, thus ensuring that FlexPower results in a win-win situation for the LBR and end-users alike.

4 Next steps

The project will continue until 2013 and will include simulation of the suggested market, and development of prognoses for both the aggregated response and for the expected price. Control strategies and algorithms for distributed energy resources will also be developed, as well as the necessary communication tools. In addition, practical tests will be undertaken in the SysLab at Risø/DTU, and with a group of one hundred real users.

References

Energinet.dk (2010): Udvilking af rammer for regulerkraft. Energinet.dk

FlexPower (2010): FlexPower project description. Available at: http://www.ea-energianalyse.dk/reports/1027_flexpower_project_description.pdf

Johansson, M. (2008): Statusrapport pr. 31. oktober 2008 for PSO-projektet Priselastisk elforbrug og elproduktion i industrien. Dansk Energi Analyse.

Nordel (2008): Harmonisation of Balance Regulation in the Nordic Countries

Veen, R. A. C. Van der, L. J. de Vries (2009): The impact of microgeneration upon the Dutch balancing market. Energy Policy 37 (2009) 2788–2797