

16-12-2011

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Design of a real time market for regulating power

FlexPower WP1 – Report 3

VERSION 2.0

Foreword

The FlexPower project investigates the possibility of using broadcasted dynamic electricity prices as a simple and low cost means to activating a large number of flexible small-scale power units. The aim is to provide regulating power via an aggregated response from the numerous units on a volunteer basis. The power units could for example be electrical heating and cooling units, electrical vehicles, industrial demand and micro generation. Each power unit can have its own local controller and individual business model and objective function. The optimisation of the local controls may require forecasts of the services requested by the customer (such as heat for a house or charging power for an electrical vehicle) – in terms of quantity, timing and flexibility – and forecasts of the electricity prices.

The responses from the individual units to variations in the electricity prices can be difficult to predict, but the aggregated response from a large number of units are expected to be relative predictable.

Based on international ‘real-time’ power market experiences, new dynamic FlexPower market mechanisms to perform regulating power are designed and tested via simulations, under laboratory conditions and in the field. A dedicated simulation tool is developed for this purpose. The FlexPower regulation can never be perfect, but is expected to be able to meet some of the present and future growing demand for regulating power.

As a starting point, a 5-minute power price signal, based on the actual regulation power prices, is tested.

The project expects to address the following questions:

- How could a system with a one-way price be designed? How can the FlexPower mechanism be integrated into the present electricity market, including the market for regulating power? (WP 1)
- To what extend and under which conditions can the aggregated response from many units be predicted? (WP 2)
- Is the use of local electricity prices an efficient way of regulating the power flow in the power distribution system? (WP 3)
- Which part, and how much of the power system’s need for regulating power can be provided by FlexPower mechanisms? How can individual technologies be controlled under FlexPower? (WP 4)

- How should communication be design to support the FlexPower idea? (WP 7)

Is the FlexPower mechanism stable and robust enough to handle disturbances? Is the use of broadcasted, dynamic electrical prices an efficient way of activating small-scale regulating power? Does it work in practice? (WP 6, WP 8, WP 9)

The project involves the following partners: Ea Energy Analysis (coordinator), DTU -Technical University of Denmark, Enfor, Actua, Eurisco, EC Power, SEAS-NVE and Nordjysk Elhandel. The work is divided into the following work packages: WP 1: Market design (Ea), WP 2: Prediction of aggregated response (DTU Informatics), WP 3: Advanced options (DTU CET), WP 4: Control algorithms (Risø DTU), WP 5: Forecasts (Enfor), WP 6: Simulation (Actua), WP 7: Communication (Eurisco), WP8: Laboratory tests (Risø DTU) and WP 9: Field tests (DTU CET).

More information at: www.flexpower.dk.

WP 1 Report 3

Design of a real time market for regulating power

Report 1 in WP 1 provided a brief historical and contextual background of the Nordic electricity market and described how the Nordic regulating power market functions in a Danish perspective.

Report 2 focused on regulating power experiences from other countries.

Report 3 builds on the previous two reports and delves into the design of a real time market for regulating power. This report describes the FlexPower concept, and gives one suggestion as to how this new market could work. How this will affect the different stakeholders is discussed, and risks and opportunities in the new market are presented.

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1) Introduction and background

With the introduction of more intermittent power generation, and reduction of the share of thermal power plants in the energy system, it's expected that there will be an increased demand for regulating power capacity. In combination with import/export to hydro power plants in Norway and Sweden, regulating power in Denmark today is primarily supplied by central power plants.

Based upon recommendations such as those from the Danish Climate Commission¹, the new Danish government has set a target of 50% of Denmark's electricity demand in 2020 coming from wind. As such Denmark is in the near future expected to greatly increase its wind power capacity. It is therefore likely that the capacity of central power plants will decrease, which means that the increasing demand for regulating power must be delivered by new resources.

Conventional power plants closing down

Many old power plant units have already been closed or are planned to close in the coming years, including:

- Ensted unit 3 and Stignæs unit 2 are closing the 1st of January 2013.²
- Studstrup unit 4 and Asnæs unit 5 closed on the 1st of April 2010.³
- Asnæs unit 3 and 4 were closed/received long start up notice in 2002.⁴
- Svanemøllen unit 1, HC. Ørsted unit 2, Amager unit 2 and Fyn unit 3 also closed recently.⁵

Demand + DERs supplying regulating power

One way of supplying regulating power capacity from new resources is to activate the demand side and/or the DERs (Distributed Energy Resources). On 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 consequence to the end-users. Eg. electricity consumption for heating or air conditioning may be converted into thermal energy (heat or cold) at one hour to provide the service (desired temperature) at some other hour; in practice, the storage of heat or cold (Schweppe, 1988).

¹ Green energy – the road to a Danish energy system without fossil fuels, Danish Commission on climate change policy, September 2010.

²TV syd: <http://www.tvsyd.dk/artikel/65862:Enstedvaerket-lukkes>

³ Business: <http://www.business.dk/transport/dong-skruer-ned-asnaes-og-studstrupvaerket>

⁴ Ingeniøren: <http://ing.dk/artikel/59023-historien-om-asnaesvaerket>

⁵ <http://www.vattenfall.dk/da/fynsvaerket.htm>

On the generation side it could be small scale generations (micro) distributed in the energy system (DERs).

Direct or indirect control Supplying regulating power via demand or DERs can be done through direct or indirect control. Direct and Indirect control can be described as:

- **Direct control** performs a direct (remote) control over its portfolio of demand/DER units e.g. based on information about market price, contract types, available transmission/distribution capabilities, etc.
- **Indirect control** can be incentives to encourage demand/DER units, such as a varying price signal resulting in a predictable aggregated voluntary response.

In the FlexPower project broadcasted dynamic electricity prices will be used to voluntarily activate (indirect control of) a large number of flexible small-scale power units, primarily consumers and DERs.

Before delving into more detail regarding the FlexPower proposal, the section below will first describe alternative ways of activating demand in the regulating power market.

Virtual Power Plant (VPP)

In a virtual power plant a number of small scale generators, storage devices and/or consumers can be controlled from one central place. In this way a central operator optimises the operation of a number of units that have enrolled in this system. The single units can beforehand set restrictions as to how they can be loaded and turned on and off, and during operation the operator can control the load of the unit(s). The operator can be either people in a control room who directly activates/deactivates units, or it can be a server, that centrally optimises the load of all units and then controls the operation of the units.

This control can be either direct, where the central operator sets the load for each unit, or it can be indirect, where the central operator sends price signals or new set points to the units. The classic virtual power plant is however usually directly controlled by the operator.

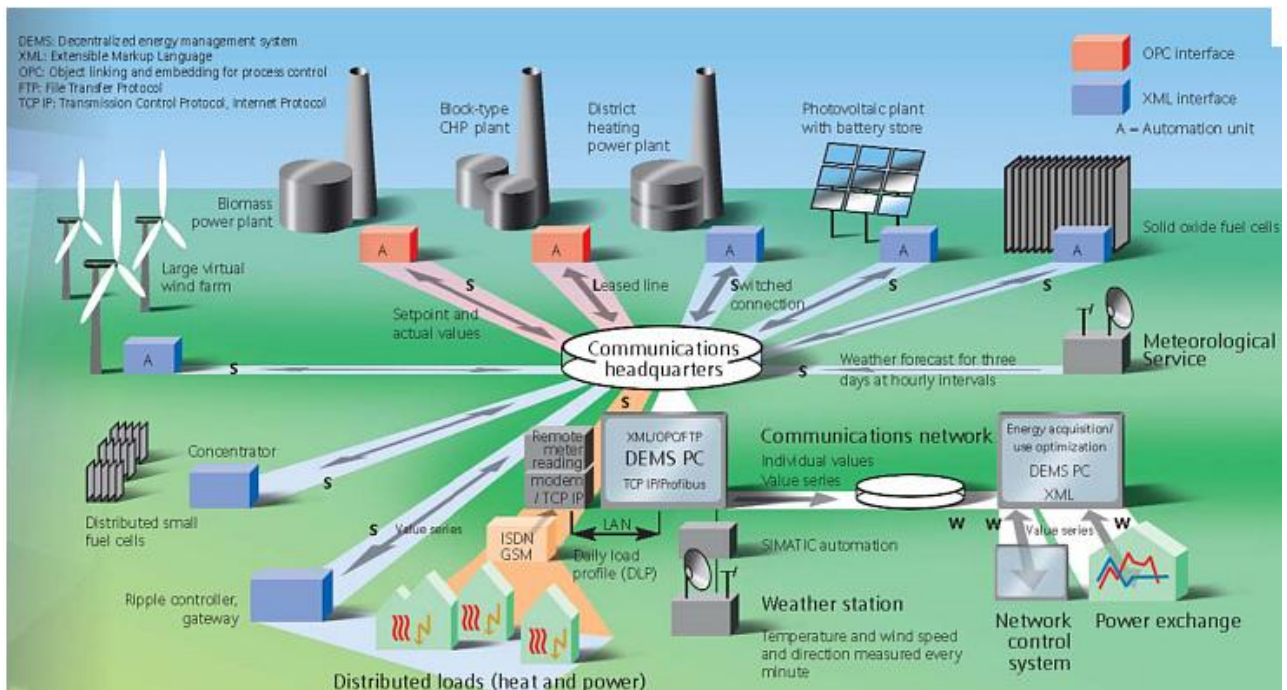


Figure 1: Illustration of a virtual power plant (Siemens 2002)

Clustering many DERs in a Virtual Power Plant is a way of giving Transmission System Operators (TSOs), Distribution System Operators (DSOs) or Balance Responsible the ability to efficiently supervise and manage a large number of distributed generation units (Salmani et al, 2010).

Virtual Power plants are also seen as a way of assisting electricity distribution and transmission grids as increasing amounts of renewable energy resources are introduced into the energy system (Barras, 2009).

Direct control

An advantage of the classic virtual power plant (direct controlled) is that the central operator can ensure that an activated regulating power bid is delivered by directly activating enough units.

Clustering results in meeting 10 MW bid demand

Another advantage is that the clustering/aggregation of many units directly makes it possible for small units to participate in the regulating power market despite the fact that there today is a minimum bid size of 10 MW in this market. An example of aggregation in the present power system is the Balance Responsible that aggregates smaller CHP plants, letting them take part in the regulating power market.

Flexitricity

The Scottish company Flexitricity is an example of a fleet operator that can control a number of DERs (e.g. standby generators and CHPs) and flexible demand units in the UK. They have access to both direct controlled units and

units with varying restrictions in the control scheme. They claim to operate the largest smart grid, delivering Short Term Operating Reserve to the UK National Grid to keep the electricity system stable during times of system stress.

Energinet.dk Proposal

In order to increase the opportunities for small scale consumption units to participate in the regulating power market the Danish Transmission System Operator, Energinet.dk, recently published a paper entitled 'Udvikling af rammer for reguler-kraft - Indpasning af mindre forbrugsenheder og andre mindre enheder i regulerkraft-markedet', maj 2010 (Development of a framework for regulating power - Incorporation of minor consumption units and other smaller units in the regulating power market, May 2010).

Manual Reserves

The paper refers to the fact that increasing amounts of wind power will require more regulating power and/or large investments in new reserves and expansion of the transmission network. Energinet.dk deems that the costs associated with large transmission expansions are considerably higher than those related to increasing the amount of regulating power. As part of its obligation to secure the best possible conditions for competition in the market, Energinet.dk shall therefore investigate opportunities for expanding the framework for the regulating power market so electricity demand and smaller units can be more active in the regulating market. The paper describes Energinet.dk's proposals as to how the framework for regulating power in particular can be adjusted. Energinet.dk envisions that these proposals shall be implemented in the upcoming years as a part of a larger move towards a 'Smart Grid', which is expected to develop over the next 10-20 years.

When discussing possible alterations to the regulating power market framework it is important to keep in mind that this market is a common regulating power market for the Nordic countries. Thus any suggested changes to the Danish market have to be seen in this larger context, a context that is expected to grow even larger as the Nordic market becomes further integrated with the European market. Given that alterations apply to more than just Denmark alone, bringing about these alterations can be challenging. That being said, Energinet.dk does foresee some potential changes. Firstly, it is likely that timeframes for regulating power will become shorter, thus increasing the flexibility of the market and moving the price setting of regulating power closer to the actual operating time. Another change could be the publication of the regulating power price during the hour of operation (as opposed to now where this price is published an hour after the operational

hour). Particularly the publication of the regulating power price within the hour could allow for greater DER participation in the market, a possibility that will be discussed in greater extent below.

Generally speaking, Energinet.dk outlines two methods of incorporating demand into the regulating power market:

1. Participate in the regulating power market under the current rules
2. Self regulating

Participation in market under current rules

As long as they fulfil the existing criteria (minimum bid size, real-time measurement, ability to re-activate, etc.), the existing market rules do allow for demand to participate in the regulating power market. However, these criteria can be quite problematic for smaller units. For example, the minimum bid size of 10 MW restricts individual units such as EVs from participating in the regulating power market. To work around this problem, on the production side there is already a tradition of Balance Responsibles pooling assets, thus enabling smaller units to participate in the regulating power market (this corresponds to a Virtual Power Plant). Energinet.dk expects, and will support, a similar development on the demand side (Energinet.dk, 2010).

Self Regulation

A more novel approach suggested by Energinet.dk is what it refers to as self regulation. The concept proposes to give consumption units the possibility to react on a regulating power price. It is intended that the regulating power price will be published within the actual operating hour as the price of most recently activated regulating power bid on the common Nordic market. By using this model the consumption units will have the opportunity to earn profits in the regulating power market by self regulation (via the balance settlement). To benefit from this system end-users must have interval meters installed.

This self regulation can also be broken down into two main categories. In the first, the Balance Responsible has remote control of some of the end-user's consumption units according to a pre-defined agreement, for example the charging of EVs, activation of heat pumps, etc. In exchange for relinquishing day-to-day control of these devices, end-users will in some way be compensated with lower electricity prices. Based on these agreements, the Balance Responsible can utilise these units to participate in the regulating power market and generate additional revenue (a current example of a Balance Responsible undertaking this approach is Nordjysk Elhandel which is utilising heat pumps in this fashion).

In the other category the load Balance Responsible settles the electricity usage according to the regulating power price. The key aspect under this approach is that no bid is submitted to Energinet.dk. The end-user simply receives a price signal and acts accordingly. As above, the price signal would be based on the latest activated regulating power bid, one each for DK1 and DK2. However, the regulating price sent out in the hour will not necessarily be the final regulating power price for that hour as this can first be determined after the fact when bottlenecks between various areas have been factored in. The risk caused by the potential difference between the price signal and actual regulating power price is one that the Energinet.dk paper states should be orientated by the commercial actors in the market as part of their business model. Under this model Energinet.dk will have the task of predicting the amount of power activated by self-regulating. Data for self regulating would be compiled and utilised by Energinet.dk in its prognosis models, i.e. determine how much self-regulation will occur given a certain price signal.

The Energinet.dk paper points out that even under the current system it is possible for load Balance Responsibles to undertake self-regulation based on estimates of what the regulating power price is likely to be. This of course involves a risk, a risk that would be lessened if the regulating power price was publicised during the operational hour.

Automatic Reserves

While the Energinet.dk paper mainly focused on manual reserves and the regulating power market, it also mentioned that if they can display the required flexibility and can react to the signals that are used to activate reserves, then consumption devices can also participate in the market for automatic reserves.

Market Design -Theory

According to Stoft (2002), for a market to reach a competitive equilibrium, at least three conditions have to be met:

1. Price taking suppliers
2. Public knowledge of the market price
3. Well behaved production costs

Price Taking suppliers

In a market where the supply side is competitive, suppliers undercut each other until they reach their marginal cost of production. A supplier is thus referred to as a *price taker* when it faces enough competition from its fellow suppliers that it can not affect the market price, and it therefore accepts to sell its good at this market price. Such a competitive market is usually comprised of numerous suppliers, of which no single player has a significantly

large portion of the market share. If a market has one or more suppliers with a significant market share, this allows them to affect the price by increasing or decreasing their output (thus influencing the supply demand balance). As a result they are not referred to as price takers, but instead are said to have *market power*. (Stoft, 2002).

Public Knowledge of the Market Price

Public knowledge of the market price (and access to market information in general) refers to the fact that traders must have access to publicly available prices from the suppliers to ensure that a competitive equilibrium can be found. This is usually not the case for bilateral trade, where the prices are only known to the two trading partners. If bilateral trades are supplementing a market with publicly available prices, and the market is substantial compared to the share of bilateral trades, then the prices for the bilateral trades will to some extent reflect the prices in the market.

Well Behaved Costs

To ensure a long-run competitive equilibrium, appropriate investments in production capacity must be made, and new players must be able to enter the market, i.e., there should be no significant *barriers to entry*. If for example there are abnormal profits to be made in a market, new players will enter the market to capitalise on these profits, thus increasing competition, and restoring the equilibrium and bringing profits to a normal level. Due to some of the unique aspects of power markets this third aspect can be problematic. However, if the above two aspects can be achieved, a relatively competitive market can be designed. (Stoft, 2002).

Liquidity

Another important aspect for a market is its liquidity, i.e., the ability to buy or sell an asset without affecting its value or price. A very liquid market would for example have enough buyers and sellers to ensure that assets can be bought and sold quickly and efficiently, i.e., with no (or very little) loss of value. This results in high credibility in the market and in the price formation.

Flex Power Design – Market Aspects

Price Taker

With respect to the first market aspect mentioned above, price taking suppliers, it is anticipated that the addition of the amount of regulating power supplied by each single FlexPower customer will be so little that it will not be able to affect the market price, and as such each FlexPower customer will be a price-taker. At the aggregated level (i.e. a retailer or load Balance Responsible actor with a large number of FlexPower customers) it is also not anticipated that such an actor will have undue market power because these aggregators will be competing with other FlexPower aggregators, as well as all other regulating power providers in the Nordic area.

Public Knowledge	In terms of having access to knowledge of the market price, the price of activated regulating power is currently publicised on the internet. The central idea behind FlexPower is to publish a regulating power price every 5 minutes, thus FlexPower will be adding to the publicly available knowledge regarding regulating power.
Barriers to Entry	With respect to barriers to entry, FlexPower is in itself attempting to remove barriers to entry by allowing more players to the regulating market, and reducing the cost and complexity involved with their participation.
Liquidity	By adding new players to the market, FlexPower will also increase the liquidity in the market, thus increasing the ability to buy and sell regulating power.

2) Outline of new market design

This chapter will describe the FlexPower idea, as well as the decisions taken regarding its design. The FlexPower idea is one way of designing a real time market for regulating power where demand and DERs can easily participate, however there are numerous alternatives and variations to such a market.

Overall Description – one way price signal for regulating power

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 for the end-user, participating in the market should be:

- Voluntary
- Simple
- Straightforward

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

Co-existence with current market

The FlexPower concept envisions that 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. The activation of bids or forwarding of price signals to the end-users must be done with respect to

congestions and bottlenecks in the distribution system. This will be discussed in WP3.

Voluntary Response

Response to the price signal is voluntary and the price signal acts as the final settlement. The price curve that serves as the basis for the 5 minute price signals is created by the Balance Responsible and incorporates the expected impact to the price signal (see Figure 2 below). It is based on past experience and historical data collected from the end-users.

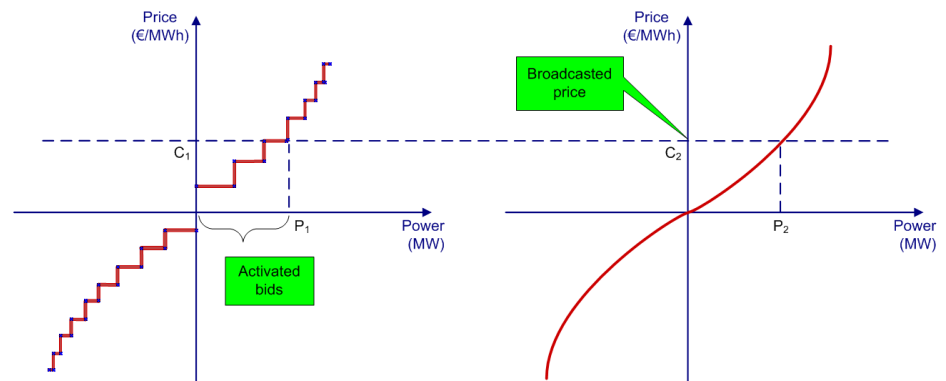


Figure 2: The current market for regulating power (left) and the suggested one-way price signal sent to the end-user from the LBR/retailer (right)

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 Flex-Power proposal comprised of many small end-users, where each end-user could be expected to supply between 1-5 kW,⁶ depending on how many are expected to react, this would require more than 10,000 users for each bid, and therefore would make it difficult to bid in with a large number of step bids (as each bid would require thousands of end-users). If however 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

⁶ The figures 1 to 5 kW are utilised as they represent effect sizes from technologies that could reasonably be assumed to be interrupted for a short period of time without affecting end-user convenience, for example heat pumps, electric vehicles, etc.

(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.

Bid free demand response

Simple for end-user

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.

To participate, end-users would typically install some automated control system that could receive the broadcasted price and realise the relevant control. The way the loads are controlled would be based on local preferences, e.g. comfort requirement such as minimum indoor temperature, min/max charging of electrical vehicles, etc.

The voluntarily aggregated reaction should be estimated beforehand by the Balance Responsible using price level, historical data about consumption (received with some days delay by the Balance Responsible/retailer), and other data, such as temperature and seasonality effects. With many end-users having automated control it is anticipated that even with the voluntary actions being taken by individual participants, the aggregated reaction from the end-users will be highly predictable. This hypothesis will be tested in WP2 which is focused on predicting aggregated responses.

Any difference from the estimate to the actual reaction is expected to be rather small and can be dealt with under existing market mechanisms. In addition, deviations from the predicted reaction could be compared to the accuracy delivered by traditional regulating power from power plants.

Straight Forward
for end-user

By making the system voluntary, not requiring bidding, and enabling a high level of automated control, the FlexPower system should be simple and straightforward for the end-user. The complexities involved with implementing the system will rest with the LBR or retailer; various aspects of which will be described later in the report.

No Reservation Price

A reservation price can be paid to Production Balance Responsibles or Load Balance Responsibles to ensure that enough regulating power is available

when needed. Historically there has been a need for this in Denmark to ensure that enough Production Balance Responsibilities would act in the regulating power market and to have sufficient volumes of regulating power available. However this may not always have to be the case, as a reservation price may not be necessary.

As can be seen in the following graphs, the reservation price of power on the regulating power market has fluctuated substantially the last 5 years. There might be a tendency of decreasing reservation prices, but it's not a very clear tendency in East Denmark.

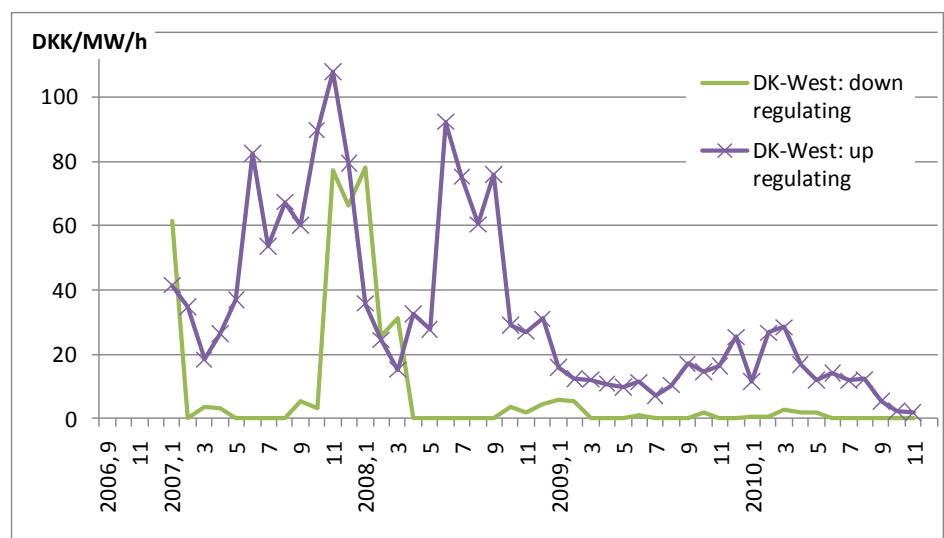


Figure 3: Monthly average reservation price in West Denmark, 2006-2010.

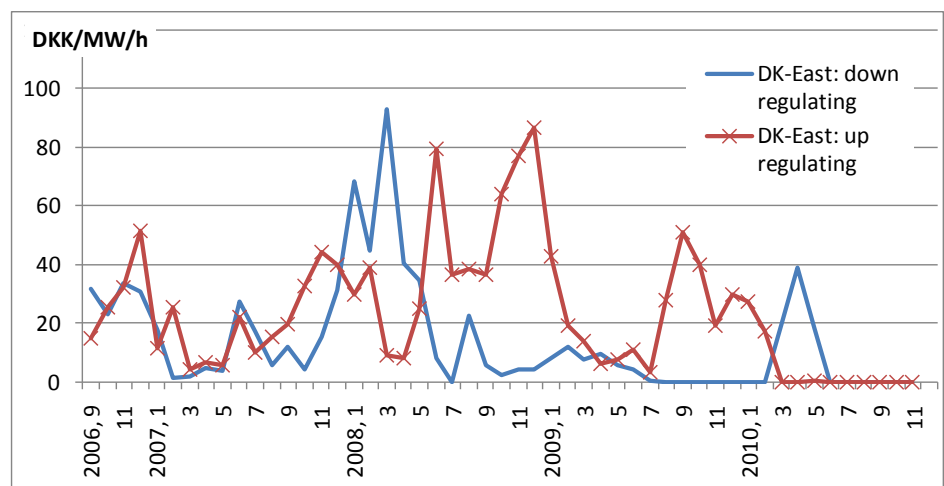


Figure 4: Monthly average reservation price in East Denmark, 2006-2010.

It is expected that the reservation price for up regulating will be high when the spot price is predicted to be high. The daily average spot price and the daily average reservation price for up regulating has been compared for one

month (see Figure 5), and the hourly spot price and the hourly reservation price for up regulating has been compared for 5 days (see Figure 6). The figures illustrate that there is a strong correlation between the spot price and the reservation price.

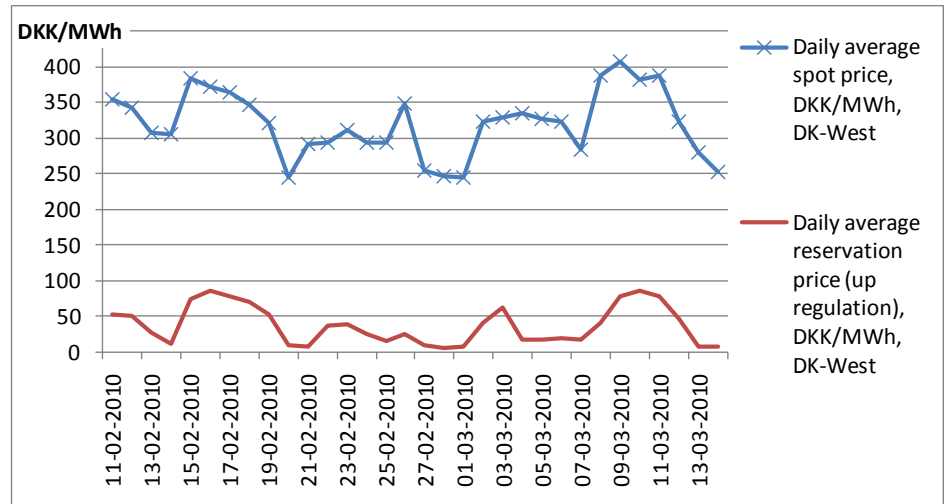


Figure 5: Daily average spot price and daily average reservation price for up regulation in DK-west, DKK/MW.

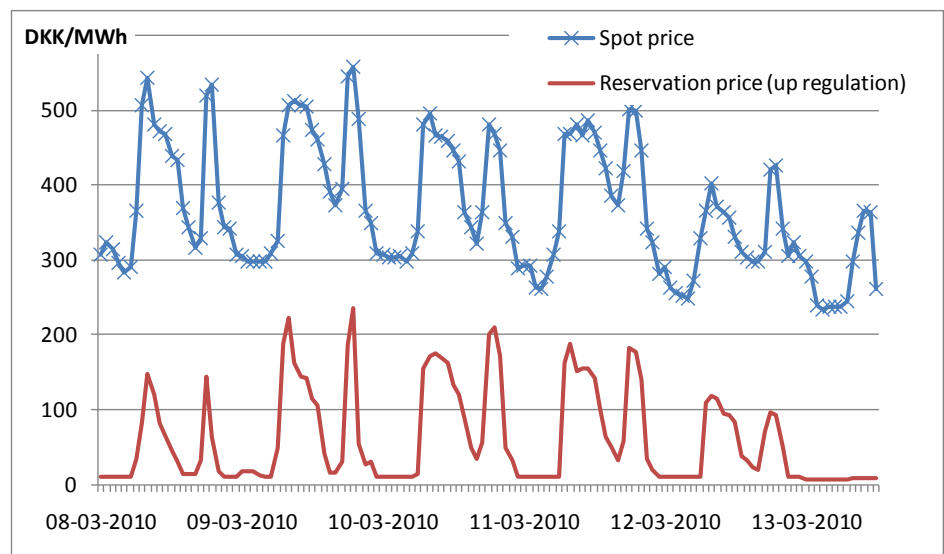


Figure 6: Hourly spot price and hourly reservation price for up regulation in DK-West, DKK/MW.

A reservation price can be used to ensure that some power is still available for up regulation after the spot market is settled. Otherwise one could risk that all generation in operation in a certain hour is on max load and therefore without ability to increase production. Central power plants not in operation will often not be able to participate in the regulating power market, since the start up time for many large central power plants is longer than 15 minutes.

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.

Who can participate in FlexPower? The Profile system

In Denmark a profiling system is used for all consumers without an interval meter. These consumers have meters that are read once a year - typically via self reading. The purpose of the profiling system is to construct hourly usage values for each end-user without interval meters. This is then used in the distribution of cost of unbalances for users with different retailers.

In short, the profiling system computes the total consumption in a DSO area minus the consumption that is metered with interval meters. This results in a profile (consumption per hour) with respect to their total annual consumption, which is shared by all end-users without an interval meter.

For consumers within the profiling system it is not possible to define a contract that awards the retailer if the end-user shifts electricity consumption to hours with low prices because without interval meters it is not possible to demonstrate that the consumption has been moved. Independent of the actual consumption, the end-user will be considered according to the profile.⁷

To be relevant for FlexPower the end-user must have an interval meter and be taken out of the profiling system, otherwise it cannot be demonstrated if the consumption has changed according to the price signals, and the end-user cannot be billed according to the actual hourly consumption.

In a few years half of all Danish end-users will have a modern electricity meter with remote reading. Today these meters are not used to record the hourly demand, but development in this direction is underway. Energinet.dk and the Danish Energy Association are discussing “a third settlement group”, where the end-user could benefit from hourly prices, and the requirements for the grid companies would be less strict than for e.g. the industrial customers with

⁷ Despite this, one retailer (Modstrøm) has offered their end-users within the profiling system free electricity during the night. They can estimate the consumption during respectively daytime / night time by using an extra interval meter (which is not an official meter used for settlement). The retailer hereby takes a risk, since they will have to pay for the consumption according to the profile (with a high share of more expensive hours during the day), but the end-users will (assuming they can move a lot of the consumption to the night hours) reduce the hours they will get billed for. Since the spot price is usually higher during the day than during the night, the price for the end-user in the day hours will probably be set higher than the normal average “all day” price. Here the retailer can cover some of the loss from not billing the consumption during the night hours. In addition the retailer hopes to gain more customers due to this product.

interval meters. The reason for this leniency is that grid companies need more time to manage the data from a large number of small customers (10-15 days compared to 3-6 days).

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.

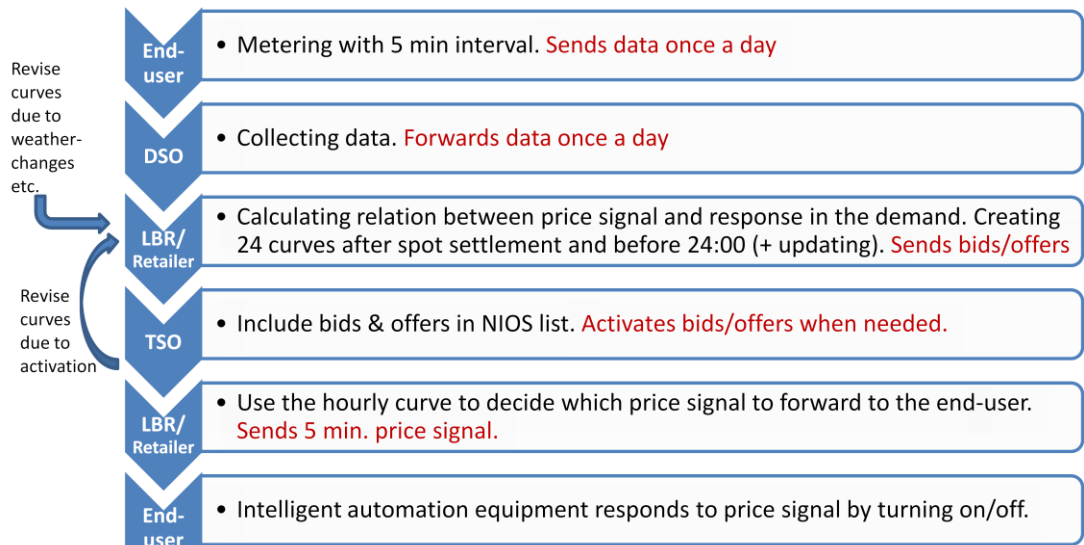


Figure 7: The FlexPower process, starting with the end-user’s data being measured and sent daily.

Metering, 5 minutes interval

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 DSO. Today interval meters are not available to all customers, but as was highlighted above, within a few years roughly half of Danish households will have smart meters installed. It is worth noting that these meters have been installed without general guidelines and standards, and might not be able to meter at 5 minute intervals. These meters will likely be able to be upgraded so that they can measure in 5 minute intervals.

Data stream

DSOs are responsible for the reading of meters, and for the newer meters this is done by the meter storing the hourly data and sending it to the DSO once a day. The DSO performs quality assurance before the data (with some days delay) are forwarded to the Balance Responsible. These data are used both for billing purposes, and as historical data to create the demand side response curves (see below). The delay is not expected to give any problems in the 2 cases.

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.

The data stream sent and the amount of stored data is quite substantial compared to today, where most meters are only read once a year. It's expected that the volume is not a technical problem, but decisions regarding how to handle this data must be made. In WP 7 the requirements for communication will be analysed, and recommendations for a communication system will be defined.

Creating the demand side response curve

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.

Since there are many end-users in the system, and they all have differences in their present condition, it is anticipated that a continuous curve can be created (see below).

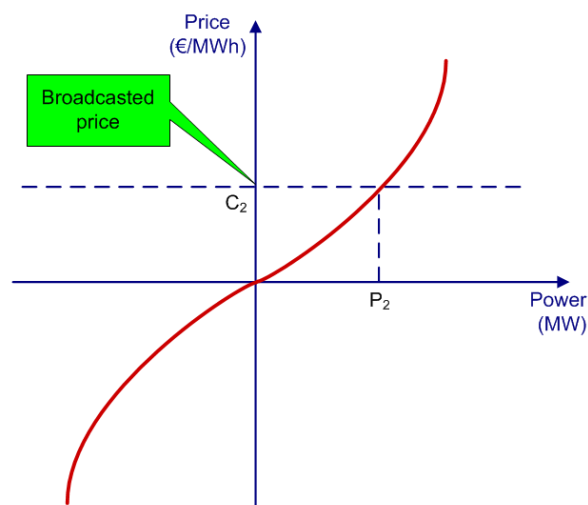


Figure 8: Broadcasted price curves

That it will likely be continuous is based on the fact that the present conditions differ from one end-user to another because there are variations in time and volume of needed consumption, and variations in end-users willingness to postpone, reduce or increase their consumption. For example, end-users will have driven different distances during a given day; will have differing heating comfort requirements, and different types of dwellings (thermal inertia), etc.

Whether this curve will indeed be continuous, or whether it will instead be stepped in nature is a hypothesis that also will also be tested (WP 2). Special conditions, e.g. specific spot price profiles, may introduce thresholds with significant reactions.

Bids and offers based on the curve

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. (Another alternative would be to send the entire curve for each hour, but this may not fit into the way the current regulating market operates). Meanwhile, up to one hour before the operating hour, the Balance Responsible can also participate in the Elbas market, as well as buy and sell electricity bilaterally. 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) 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). The bids (and offers) based on the curve could look as those depicted in Figure 9 on the following page.

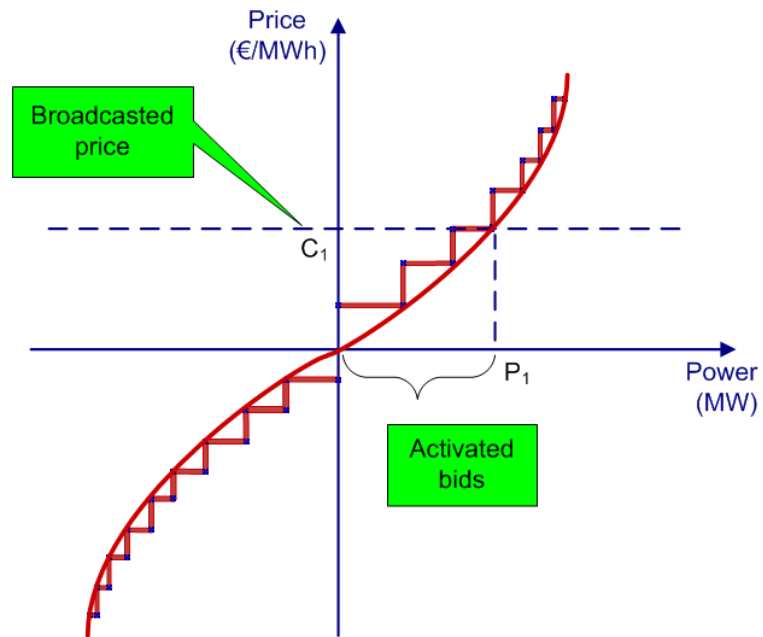


Figure 9: The bids and offers are shown as steps in the graph. The area between the steps and the graphs represents the profit to the Balance Responsible. It could be argued that the steps will be closer to the graph, or even crossing the graph. This depends on the risk willingness from the Balance Responsible.

Activation of bids and offers

When an imbalance in the system occurs, bids or offers from the list are activated by the TSO and the corresponding Balance Responsible is contacted. If there is a deficit in the system, offers of up regulation (equal to reduction of consumption) are activated in the regulating power market, and the Balance Responsible is asked to activate one or more of their offers of up regulation. If there is a surplus in the system, bids of down regulation (equal to increase of consumption) are activated in the regulating power market, and the Balance Responsible is asked to activate one or more of their bids of down regulation. When a bid or offer is activated, the regulation must be fully active within 15 minutes. Dependent on the reaction time the price may be increased in one, two or three steps to gradually realise the activation within the 15 minutes. Currently, activation of regulating power should be linearly ramped up, and this is also assumed to be the case for FlexPower.

Activating the end-users

The Balance Responsible then sends out a price signal to the end-users participating in the FlexPower system. The price signal could for instance be sent via SMS, sent through the internet, or broadcasted on a web site. This will be discussed in WP 7. In determining the size of the price signal, the Balance Responsible refers to its experience curves. This price signal is what based on

experience can be calculated as being sufficient to achieve the desired demand side reaction.

In order for the subscribers to react fast enough the price signal should be broadcasted with a shorter time interval than regulating power has (the 15-minutes notice). Therefore the fixed 5-minute time intervals are suggested (e.g. 12:00, 12:05, 12:10, 12:15,...). If a bid from the Balance Responsible is activated by the TSO at for example 12:03, the Balance Responsible can not send out the corresponding price signal to the end-user until 12:05.

Since the bid/offer to the regulating power market activated from the TSO is with 15 minutes notice and price signals are sent every 5 minutes, there are two different strategies that can be applied.

- If the TSO prefers a demand response as quick as possible, the price signal corresponding to the activated bid/offer can be sent out in the first and following 5 minute intervals.
- If the TSO prefers the demand response to ramp up gradually over the coming 15 minutes, different price signals can be send out in the first 5 minute interval and the following 5 minute interval.

(DKK/MWh)	Spot price	Regulating power	Price signal quick	Price signal ramp up/down
12:00	300	300	300	300
12:03	-	500	-	-
12:05	-	-	500	370
12:10	-	-	-	440
12:15	-	-	-	500
12:20	-	-	-	-
12:21	-	300	-	-
12:25	-	-	300	370
12:30	-	-	-	430
12:35	-	-	-	300

Table 1: Illustration of price signals. From 12:03 to 12:21 up-regulation is needed. No regulating power is needed before and after this period. “-“ indicate same price as time step before.

Flex Power users respond to price signal

Optimisation at end-user At the FlexPower end-user, equipment with automation will include the new price signal 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.

Prognosis

The local computer may compute a prognosis for the regulating power price to reduce risk. If electricity demand for example only can be disconnected for a limited time, the expected future price is important. Local control algorithms are studied in WP4.

Regarding payment, the consumption should be metered with 5-minutes intervals and payment arranged at a later day (see *Financial process*).

Aggregated Response

The aggregated response from all end-users to a new higher price (up regulation, which equals to demand for a reduction of consumption) can either:

- Equal the forecasted. The end-users reduce their consumption according to the bid amount from the Balance Responsible.
- Be greater than forecasted. The Balance Responsible has now provided more up regulation than required.
- Be less than forecasted. The Balance Responsible has not provided the up regulation required.

It is expected that with a large number of participants in FlexPower, the aggregated response will be close to the forecasted, which as was highlighted above, is a hypothesis that will be tested. The algorithms calculating the aggregated expected response will be updated regularly. If the actual aggregated response differs from the expected response, this difference can not be registered immediately. However, this is nothing new as total consumption will usually differ from the expected consumption. If the TSO observes (in the operating hour) that there is still a general unbalance after activation of regulating power by means of a FlexPower offer, this can be due to:

- The FlexPower participants not responding as expected.
- Other end-users demanding more or less than expected.
- Power plants generating more or less than expected.
- Other regulating offers not responding as expected.
- Connections to other bidding areas providing more or less electricity than expected.

If the unbalance is too high, the TSO will activate the next bid/offer from the NOIS list, which can either be a generation side bid/offer, or a demand side bid/offer from FlexPower.

4) Financial process

The financial interaction between different players can be illustrated as below in Figure 10.

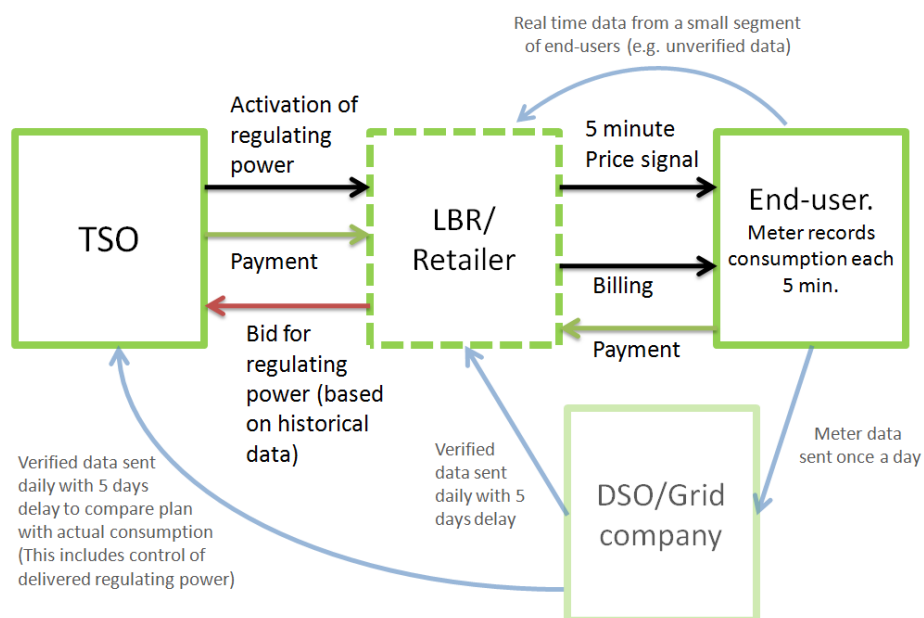


Figure 10: Overview of the financial interaction between different players.

Starting in the centre of Figure 10 and following the arrows:

- The LBR/retailer sends bids/offers to the TSO based on the historical consumption data.
- When there is a need for regulating power the TSO activates bids and offers, and there is a payment to the LBR/retailer afterwards.
- The LBR/retailer reads the curves calculated based on the historical consumption data to determine what price signal is adequate for obtaining the demanded response. The price signal is sent to the end-user.
- The end-users automatically respond to the price signal by changing consumption. The resulting consumption is read in the meter and data are sent once a day to the DSO.
- The DSO forwards the meter data to the LBR/retailer after quality assurance.
- The LBR/retailer bills the end-user.
- The end-user pays the LBR/retailer.

Financial process for the end-user

For the FlexPower end-user, the real-time price signal sent by the balance responsible is the settlement price. At times when there is no need for regu-

lating 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 the product of the amount of electricity used and the real-time price signal. The 5 minute interval consumption values are stored in the meter and sent to the DSO, and hereby to the LBR/retailer, for instance once a day. The LBR/retailer has stored the real-time price signal sent to the end-user, and after receiving the 5 minute consumption data can calculate the product of consumption and price for each 5 minutes interval. These figures are then summed together, and a bill can be sent for each billing period.

With the metering and billing being done remotely, and the actual response to the price signals being carried out automatically according to pre-determined criteria, the entire process is extremely simple for the end-user.

Financial Process for the Balance Responsible

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

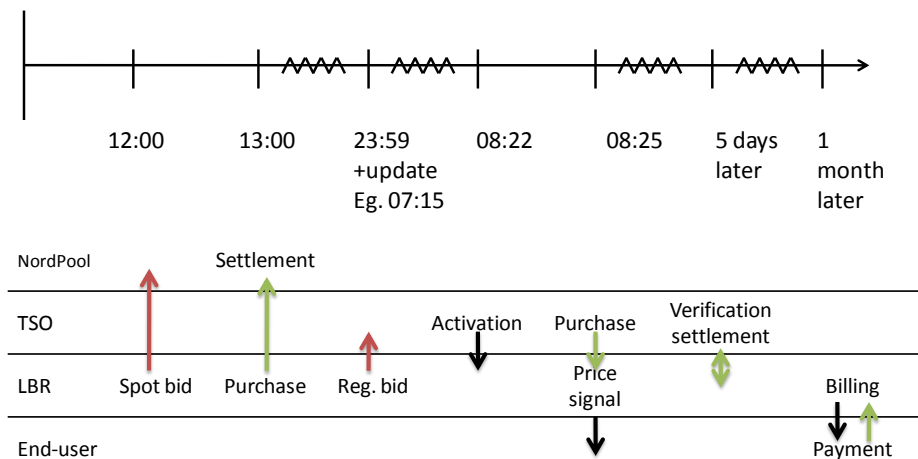


Figure 11: Timeline of events under the FlexPower setup

Assuming that the LBR purchases its electricity on the NordPool 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 is 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. If the LBR's customers utilised more electricity than the LBR had purchased, then the LBR must pay the TSO for the amount of additional electricity used, and the price will be the regulating power price for that hour. If the bidding area as a whole had excess electricity (was in need of down regulation), the price paid for the excess electricity (the regulating power price) will be equal to or less than the spot market price. If however the bidding area had an electricity deficit (in need of up regulation), then the regulating power price will be equal to or higher than the spot market price.

If the opposite is true, and the LBR's customers utilised less electricity than the LBR had purchased (in the spot market and the regulating power market), then the TSO must pay the LBR for this difference, and the price will once again be the regulating power price for that hour.

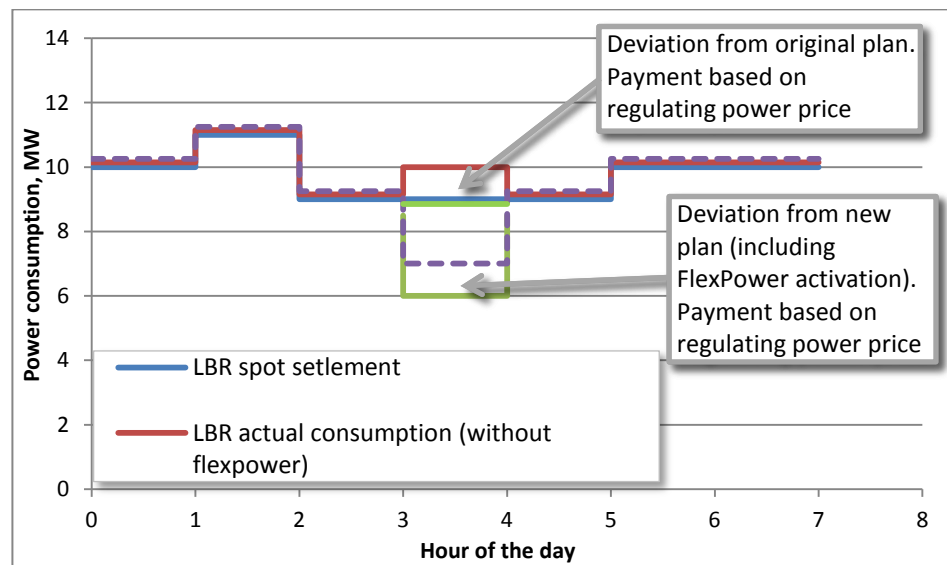


Figure 12: Shows that both the amount and the price for an unbalance is the same for a deviation due to a change in the original plan, or due to FlexPower not responding to a new price signal as expected.

As can be seen in Figure 12, the two small rectangles (the area between the red and the blue line and the area between the green and the dotted purple line) are of the same size. This reflects the fact that an unbalance that arises from a deviation between plan and actual consumption can easily be the same with and without FlexPower. The penalty paid for the unbalance is in both cases based on the regulating power price. This means that it does not matter if the unbalance is due to the FlexPower price signal not resulting in

the forecasted response, or simply due to deviations in consumption occurring because of poor forecasting of demand.

With respect to the FlexPower users, as was outlined above, in its simplest form the LBR could simply charge them for the amount of electricity used in each 5 minute interval, with the price being the 5 minute real time price signal from the TSO. The real time price signal from the TSO is understood as the regulating power price when regulating power is activated and otherwise as the spot price. Due to the risk taken by the LBR, the price signal to the end-users will probably differ from the real time price signal from the TSO. (Risks and opportunities will be described in the next section)

There are additional aspects that the LBR must also consider when determining their business model, with these aspects each introducing potential risks and opportunities. This will be further elaborated in the following chapter.

5) Risks and opportunities

Risks for the Load Balance Responsible

Two risks for the LBR are identified and described below:

- The deviation in settlement between the TSO and the LBR compared to the settlement between the LBR and the end-users. This is due to the fact that the end-user participating in FlexPower will pay the same price for the total consumption within a 5 minute interval, whereas the LBR will buy part of it on the spot market and part of it via the regulating power market.
- The duration of an activation will affect the costs of maintaining the same level of activated regulating power, and hereby it will change the curve the longer the activation lasts.

Deviation in settlement between TSO/LBR and LBR/end-user

The price signal that the LBR sends out to its FlexPower customers applies to their entire power usage. However the LBR has bought some of this on the spot market, and some via the regulating power market. Therefore the LBR incurs a risk that they will have paid more on 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 on the spot market for a higher price.

Why does the price signal that the LBR sends out to its FlexPower customers have to apply to the customer's entire power usage? The reason for this is a combination of factors:

- The end-user does not send a plan for their consumption or bids for regulating power or promise any special behaviour / certain consumption. There is therefore no such thing as 'expected consumption'/'planned consumption'/settled plan when you look at the single end-user level. There is only a plan at the LBR level.
- Only end-users with some automated flexibility in their demand are expected to sign up for the FlexPower price, but most of these end-users will still only have one meter for the total consumption, and not one meter for the non-flexible demand and another one for the flexible demand.

Due to there being only one meter per end-user and no settled plan for consumption for the single end-user, the end-user cannot pay the spot price for a

part of the consumption and the regulating power price for another part of the consumption at the same time. Therefore when participating in Flex-Power, the end-user will have to pay the regulating power price specified by the Balance Responsible at a given time for the total consumption. Whenever the TSO has activated a regulating power bid to the Balance Responsible, and the Balance Responsible has sent a price signal to the end-user, this price signal is the power price for the total consumption. The five minutes price is the final settlement for the total consumption.

This however differs from the settlement procedure between the TSO and the LBR. In an hour with up regulation, where the TSO has activated an up regulation bid at a LBR, the LBR has bought some of the power consumed in that hour on the spot market, and some via the regulating power market.

Due to the deviation in settlement procedure between TSO->LBR and LBR->end-user the LBR incurs a risk.

Example

To understand the dynamics and risks of entering the FlexPower market, a series of simple examples are designed (cases 1-4). In all examples the spot price is assumed to be 300 DKK/MWh (all day) and up and down regulating is assumed to cost 500 and 100 DKK/MWh respectively. It is also assumed that the reaction in demand to prices can be described with an elasticity of 25% in the examples (if price increase with 100%, demand is reduced by 25% and vice versa for price reductions).

With an expected consumption of 100 MWh/h, a down regulation price of 100 DKK/MWh for one hour will then result in an increase in the consumption of 16.67 MWh/h and a resulting total consumption of 116.67 MWh/h.⁸ An up regulation price of 500 DKK/MWh will for one hour result in a decrease in consumption of 16.67 MWh/h and a resulting total consumption of 83.33 MWh/h.

In an hour of down regulation, the end-user will pay $100 \text{ DKK/MWh} \cdot 116.66 \text{ MWh/h} = 11,666 \text{ DKK/h}$ for the total consumption.

In an hour of up regulation, the end-user will pay $500 \text{ DKK/MWh} \cdot 83.33 \text{ MWh/h} = 41,666 \text{ DKK/h}$ for the total consumption.

⁸ A price reduction of $300 - 100 = 200 \text{ DKK/MWh}$, for a percentage change of 66.7%. Given an elasticity of 25%, this gives a change of consumption of 16.67 MW.

In an hour of down regulation, the LBR will pay $300 \text{ DKK/MWh} * 100 \text{ MWh/h} = 30,000 \text{ DKK/h}$ for the (spot market) settled consumption + $100 \text{ DKK/MWh} * 16.66 \text{ MWh/h} = 1,666 \text{ DKK/h}$ for the extra consumption.

In an hour of up regulation, the LBR will pay $300 \text{ DKK/MWh} * 100 \text{ MWh/h} = 30,000 \text{ DKK/h}$ for the (spot market) settled consumption - $500 \text{ DKK/MWh} * 16.66 \text{ MWh/h} = -8,330 \text{ DKK/h}$ for the reduction in consumption.

	Spot	Down	Up	Total Down	Total up
	DKK/MWh* MWh/h	DKK/MWh* MWh/h	DKK/MWh* MWh/h	DKK/h	DKK/h
LBR	$300 * 100 = 30,000 \text{ DKK/h}$	$100 * 16.66 = 1,666 \text{ DKK/h}$	$-500 * 16.66 = -8,330 \text{ DKK/h}$	31,666	21,670
End-user		$100 * 116.66$	$500 * 83.33$	11,666	41,666

Table 2: Example of costs for the Balance Responsible and FlexPower customers for an hour of up or down regulation.

All 4 cases look at the costs for the LBR and for the end-user during a 24 hour period. In case 1 there is no regulation, in case 2 there is four hours of up regulation and four hours of down regulation, in case 3 there is two hours of up regulation and four hours of down regulation, in case 4 there is four hours of up regulation and two hours of down regulation.

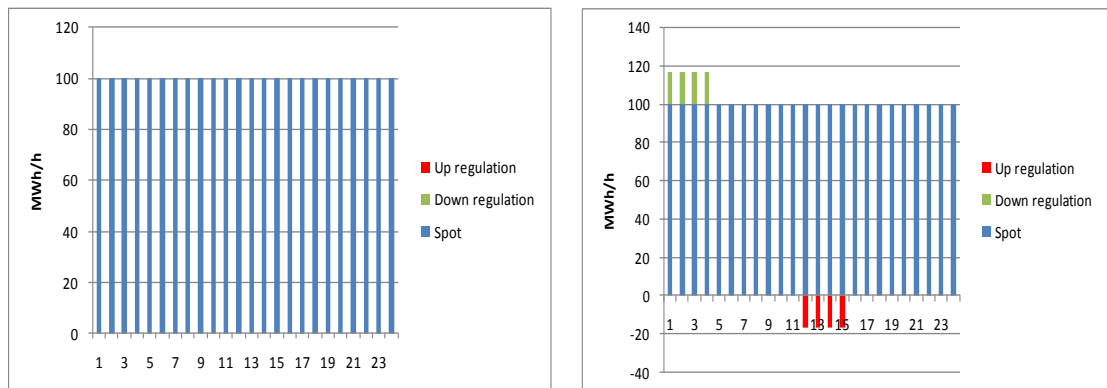


Figure 13: Cases 1 and 2: Case 1, no regulation. Case 2, the same as case 1, but with four hours with up regulation and four hours with down regulation.

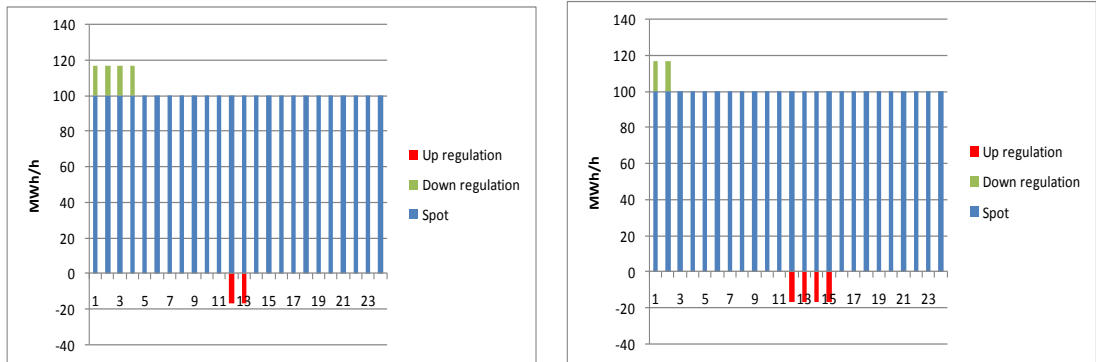


Figure 14: Cases 3: As case 2, but only with two hours of up-regulation. Case 4: As case 2, but only with two hours of down-regulation.

Case	Spot	Down	Up	Total
1 – Balance Responsible	720,000	-	-	720,000
1 – FlexPower	720,000	-	-	720,000
2 – Balance Responsible	720,000	6,667	-33,333	693,333
2 – FlexPower	480,000	46,667	166,667	693,333
3 – Balance Responsible	720,000	6,667	-16,667	710,000
3 – FlexPower	540,000	46,667	83,333	670,000
4 – Balance Responsible	720,000	3,333	-33,333	690,000
4 – FlexPower	540,000	23,333	166,667	730,000

Table 3: Example of costs for the Balance Responsible and FlexPower customers under the 4 cases. Note: For FlexPower the cost in the column Spot is the cost of electricity in hours without regulation.

Discussion

Traditionally, regulating power is defined only as the difference in volume between planned demand and revised demand. The price for up regulating power is paid only for this difference in volume.

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. As was highlighted above, 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.

As illustrated in cases 1 and 2, there can be a balance between Balance Responsible payment and FlexPower payment. This is the case when the number of up regulation hours is equal to the number of down regulation hours, AND when the up and down regulation price is symmetrical (as assumed here). In other situations the Balance Responsible will have a loss or a profit. E.g. in case 3 the Balance Responsible loose 40,000 DKK, and in case 4 the Balance Responsible have a profit of 40,000 DKK.

In general the volume of up and down regulating power is in the same order – however there is no guarantee that this is the case in all periods. The difference between up regulating price and the spot price is often higher than the difference between spot price and down regulating price. This will result in a profit for the Balance Responsible.

Example

Two examples showing the potential profit/loss for the Balance Responsible are illustrated with the following 6 graphs. In the examples either two up regulating power offers or two down regulating power bids are activated within the same hour. The up regulations are offers at 500 and 700 DKK/MWh and the two down regulations are bids at 200 and 100 DKK/MWh, as in the first two graphs:

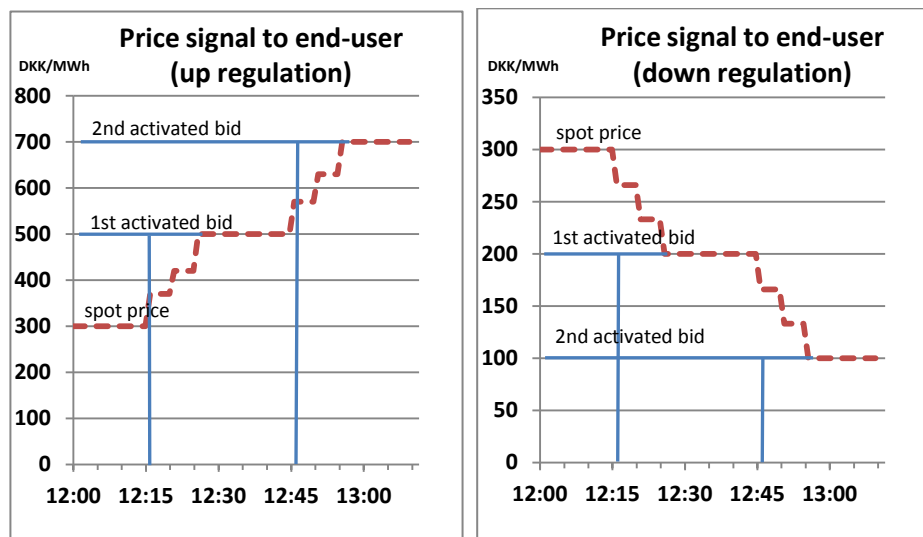


Figure 15: An hour where two regulating power bids/offers are activated. The activated bids/offers are shown as blue lines. The corresponding price signals to the end-users are shown as the red step-shaped curve. First graph showing an example of up regulation. Second graph showing an example of down regulation.

Due to the change in price signal, the end-users consumption will change. In this example it is assumed that the demand response is app. 25% of the consumption at a 100% change in price signal. This is illustrated in the following two graphs:

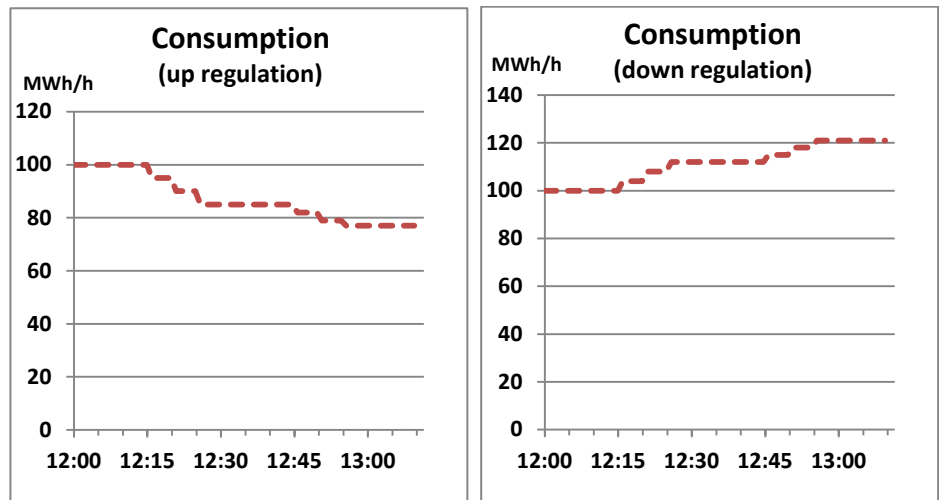


Figure 16: An hour where two regulating power bids/offers are activated. The demand response to the price signals in figure 13 (resulting from the activated bids/offers) are shown as the red lines. The first graph shows an example of up regulation. The second graph shows an example of down regulation.

The payment from end-user to LBR and from/to the LBR are calculated and shown in the following graphs as the areas under the graphs. It's assumed that the payment to/from the LBR is for the actual consumption and actual activated bid in each 5-min interval and not the highest activated bid in the hour, as it is today.

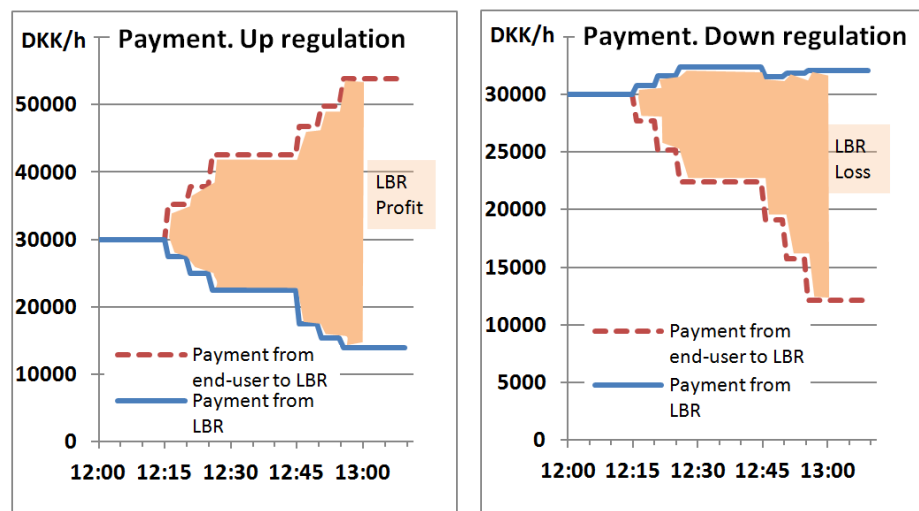


Figure 17: An hour where two regulating power bids/offers are activated. Payment for end-user and payment for LBR. The area between the graphs represent the potential profit/loss in the two examples. The first graph shows an example of up regulation and the second graph shows an example of down regulation.

As illustrated in the graphs in Figure 17, the deviation between payment from end-user to LBR and from the LBR is rather high (the area between the curves). However, given the assumed prices on activated bids, price signals

and consumption size response to the prices signals, the deviation is larger during up regulation periods rather than during down regulation. This makes room for a net profit for the LBR.

Duration of an activation will affect the curve

The LBR computes (based on historical data) curves for each hour showing the correlation between the amount of activated regulating power and the price signal necessary to send to the end-users to achieve the activated regulating power. One additional challenge in calculating this correlation 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, after a while some of these demands will need to start consuming regardless of the price. This could be a cooling unit that at first is inexpensive 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. Now another (and more expensive) unit must be activated to maintain the same volume of regulation. It can be illustrated as the graph being steeper and steeper the longer the activation lasts.

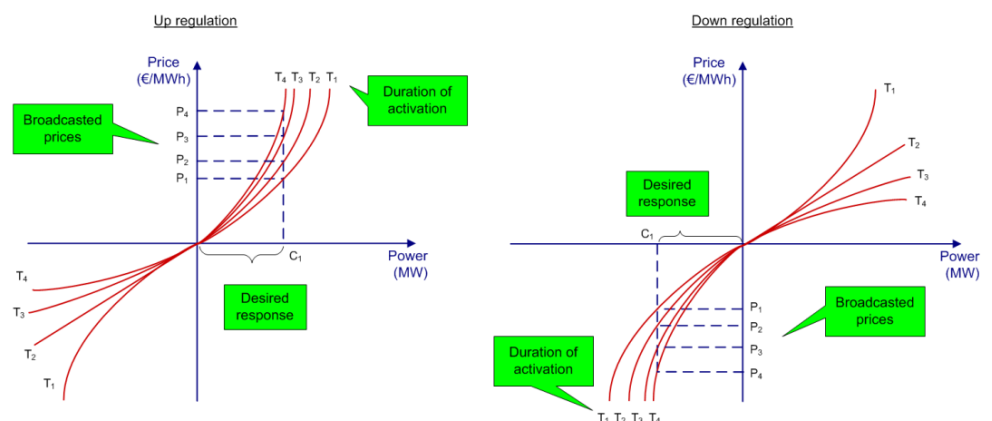


Figure 18: Curves showing the relation between the desired demand response and the necessary price signal for a regulation. The longer the duration of the activation lasts, the steeper the curve for a regulation will be.

The LBR needs to take this risk into account when sending regulating power bids and offers to the TSO because when the bids and offers have been activated, the LBR needs to deliver the regulating power or pay the penalty for unbalances afterwards. One thing that reduces this risk is the LBR's possibility

to change the regulating power bids and offers for the next hour. In this way the risk is only for a maximum of one hour.

Opportunities for the Load Balance Responsible

Ramping up

An opportunity for the LBR is the different possibilities with respect to 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. 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, but still within the restriction from the TSO.

The LBR has to take the response time into account. Most demand will probably respond very quickly, but some will have a longer response time. It can be an advantage that not all demand responds instantaneously. This will be further investigated in WP 2.

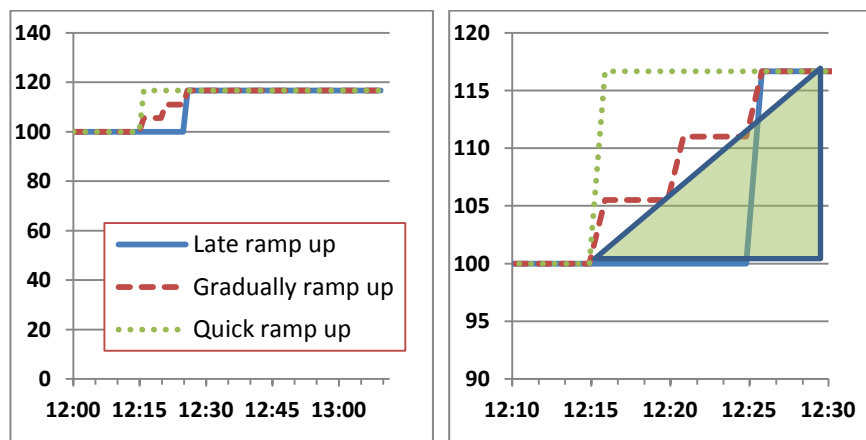


Figure 19: Example of down regulation. The first graph shows the consumption in MWh/h, the next one showing a detail, where the change in consumption usually expected by the TSO is shown as a green triangle.

Settlement price is that of highest/lowest value bid activated

Another aspect that the LBR must consider when designing its business model is that 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.

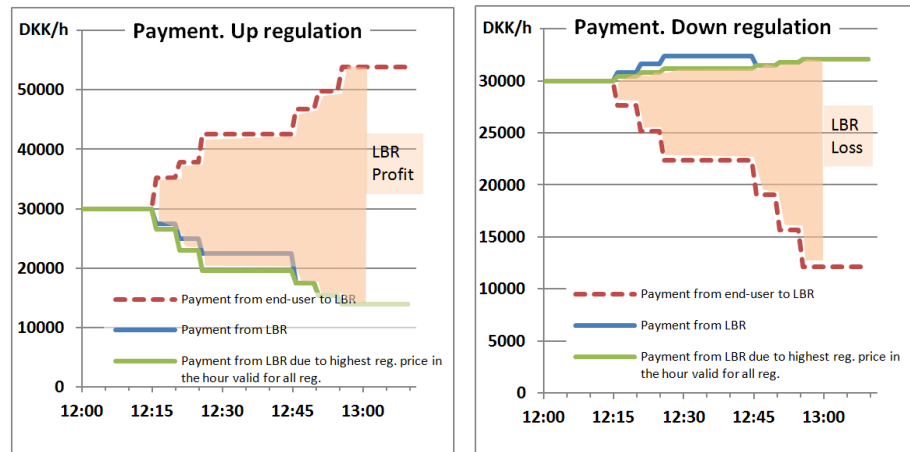


Figure 20: An hour where 2 regulating power bids/offers are activated. First graph showing up regulation. Second graph showing down regulation.

Explanation of Figure 20: The payment from the end-user to the LBR and from the LBR to the TSO is the areas under the graphs (Assuming the payment is for the actual consumption, but the price is based on THE HIGHEST activated bid in the hour for the LBR, as it is today). Assuming an initial consumption of 100 MWh, spot price of 300 DKK/MWh, 1st up regulation of 500 DKK/MWh 2nd up regulation of 700 DKK/MWh, 1st down regulation of 200 DKK/MWh, 2nd down regulation of 100 DKK/MWh, and demand response app. 25% at 100% change in price.

The potential extra profit for the LBR can be seen as the area between the gray/blue and green lines to the left in Figure 20, whereas the extra loss for the LBR can be seen as the area between the blue and green lines to the right in Figure 20.

Up and down regulation within the same hour

It is also possible to have a situation where both up and down regulation are activated within the same hour.

For the end-user such a situation will simply lead to price signals that change from “higher than spot” to “lower than spot” within the hour. This is unproblematic, as the settlement with the end-user is for each 5 minute intervals. The consumption in a 5 minute interval with up regulation is settled with the end-user at the up regulation price and vice versa for down regulation.

The LBR is paid the highest up regulating price for the time period where up regulation is activated and if the same LBR is activated for down regulation in

the same hour, the lowest down regulation price will be paid for the time period where down regulation is activated.

Evaluation

Special evaluation procedures may be needed to ensure that the Balance Responsible sends accurate bids to the spot market as well as bids to the regulating power market. There could be monthly evaluation of the accuracy of the bids.

6) Discussion - Stress test - and open questions

Price signal sent to FlexPower participants by TSO or by an intermediary (LBR)?

If this new regulating power market (FlexPower) was to be constructed without an intermediary, the TSO should make the curves showing the response in demand to certain price signals, and take this additional regulating power into consideration when choosing the volumes of selected bids. For end-users, the advantage of such a system would be that profit to the LBR intermediary would be removed. For the TSO, the advantage would be that they would have the complete overview of activated bids/demand side response. The disadvantage is that the financial risk is placed on the TSO and not the LBR, and that payment is complicated, since the TSO is activating + paying for regulation, but the TSO does not have billing contact to the end-users.

Immediate feedback from a small segment of end-users

In the initial stages of the development of the FlexPower concept it was envisioned that the end-users' response to price signals could be adequately forecasted based solely upon historical data. However, during the development of the tools to be utilised in sending out end-user price signals, it became apparent that a feedback loop with more immediate information from a segment of the end-users would greatly improve this process. As such, it is envisioned that the LBR as part of its business model will choose to install real-time meters at a small percentage of its customers, thus allowing the LBR to incorporate this feedback into its ongoing price signal calculations.

This additional feedback data would be unverified data and thus not suitable for billing purposes, however it would serve as a valuable input in the ongoing calculation of price signals and provide immediate demand response feedback.

Separate metering for the flexible and inflexible load?

One of the largest risks associated with the current FlexPower set up is that the price of electricity applies to the entire load, not just the flexible load. Other actors, including Energinet.dk and Dong, have discussed a model where separate meters are installed for the flexible portion of an end-users' consumption.

While such a model would reduce some of the risk and uncertainty, it also complicates the process as it requires additional metering for each of the flexible loads, and separate billing arrangements for the flexible and inflexible loads. At this point in time the FlexPower concept has elected to maintain a straightforward approach that thus involves a single meter, and a single billing arrangement.

Will the LBR deliver more regulation than is needed?

Does the LBR have an incentive to produce more up or down regulation than is needed/activated? Today the two price system (see report 1) only applies for generation side regulating power. When the demand side delivers up regulation (reduces demand), the LBR is always paid the regulating power price for the reduction compared to the Spot settlement, regardless if more or less up regulation is delivered compared to the activated bid. This could create an incentive to 'overshoot'. For FlexPower to function in a more optimal way, it could be appropriate if the two price system is utilised.

Will too many FlexPower users react at the same time?

With a lot of identical consumption units in the system it could be expected that they will all react to the same price signal. This would turn the continuous increasing curve into a step wise shaped curve. Initially this is not expected to give rise to problems due to two facts:

1) Even though a lot of consumption units are identical, they will have different consumption patterns. For electrical vehicles there will be differences in how long they have driven the day before, and hereby different needs for charging time. There will be different demands for at what time they will be used next time, and therefore different needs for latest start time for charging. For heating there will be differences in the building envelope and in the demanded comfort level. For cooling there will also be different use of the devices.

2) If there should anyhow appear step wise shaped price curves, this will probably not give rise to big problems, since the bid/offer structure in the regulating power market is at present based on bids and offers 10 MW in size.

The step size is expected to be rather small, but this will be further investigated in WP2.

How to handle bottlenecks in the local grid?

If for example many electrical vehicles in a local area are charging at the same time, there might arise problems with bottlenecks in the local grid. These kind

of problems could be increased with the introduction of FlexPower inviting many consumers to react to price signals at the same time.

To reduce this type of bottleneck problems one solution could be that the DSO/grid responsible is given a possibility to add flexible grid payment to the FlexPower price. This will be further investigated in WP3.

Improved optimisation at end-user with access to price prognoses

In FlexPower it is anticipated that only the current price signal is sent to the end-users from the LBR. However the end-user will need some kind of prognosis for the price signals in order to determine if a given price signal is high (low) enough to switch off (on) electronic appliances. The prognosis can be as simple as two set points indicating what is considered to be a high/low price. Alternatively, it could be a prognosis delivered from e.g. the retailer each day, or from an independent prognosis producer. Controllers at the end-users can be more or less advanced and hereby some of them will be able to receive prognoses and use them intelligently, while other controllers might not. This will be further examined in WP4.

To determine at what time a specific volume of consumption should take place, the decision making process could be optimised if the end-user several times a day (perhaps each hour, or even more often) received a prognosis for the 5 minute prices for the next hour / couple of hours.

Example

For example, lets assume that the end-user plans to consume 10 kW for 30 minutes within the next hour and there are two activated up regulations within the next hour. The spot price is 300 DKK/MWh, the first up regulation is at 500 DKK/MWh, and the next one at 700 DKK/MWh. If only the price signal is sent out to the end-user, the end-user will stop using electricity when the first 500 DKK/MWh price signal is sent out. After 30 minutes the end-user will need to start consuming electricity again. The payment is shown as the area under the blue line in Figure 21. This payment will be high due to the second activated up regulation.

However, if the end-user knew (or received a prognosis which indicated) that two up regulations would be activated within the hour, then the end-user would *not* stop using electricity when the first price signal (500 DKK/MWh) is sent out, but instead wait to stop until the 30 minutes of needed consumption was over. The payment for this more intelligent consumption strategy is shown as the area under the red line in Figure 21. This payment will be the lowest possible for that hour.

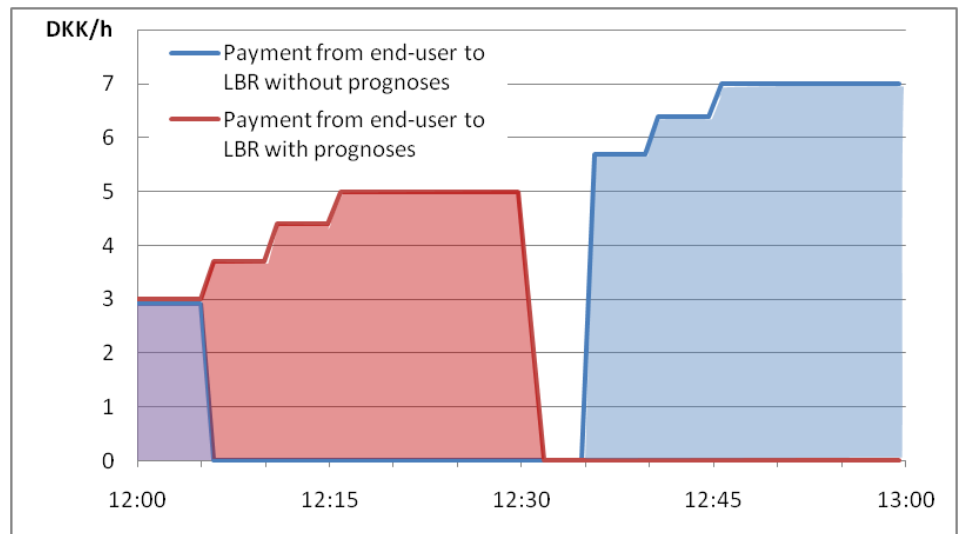


Figure 21: Payment for 30 minutes consumption with and without prognosis.

The payment when “only” the price signals are sent out is shown via the purple + the blue areas in Figure 21 and is equal to 3 DKK for that hour. The payment if the end-user had access to a perfect prognosis is shown via the purple + the red areas in Figure 21, and has a value of 2.1 DKK for that hour. A prognosis could in this example have saved the end-user for $3 - 2.1 = 0.9$ DKK.

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