Ea Energy Analyses

23-05-2012

C. Bang, F. Fock, M. Togeby

The existing Nordic regulating power market

FlexPower WP1 – Report 1

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-minutes 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 1

The existing Nordic regulating power market

This report is the first of three reports in Work Package 1 and sets the stage for reports 2 and 3. The initial portion of the report provides a brief historical and contextual background of the Nordic electricity market. Thereafter it goes into greater detail describing the Nordic regulating power market, both how it functions in practice, and examining some of the historical trends from a Danish perspective.

Report 2 focuses on regulating power experiences from other countries, and Report 3 builds on the previous two reports and delves into the design of a real time market for regulating power.

Content

Foreword **2**

The existing Nordic regulating power market 3

Overview **5**

Historical background 5

Relevant Actors and their Roles 6

Nordic Market Structure 10

Financial market 10

Day-ahead: Spot Market 10

Intra Day: Elbas Market 12

Reservation Markets 13

Other Reserves 13

Regulating Power Market **14**

Activation of regulating power 16

One-price and two-price balance settlement systems 17

Limitations of current regulating market 18

Market Aspects 20

Regulating Power: Hours 20

System Balance and Import/Export 22

Difference between regulating power price and spot prices 23

Difference between regulating power price and spot prices: Value 29

Duration of Regulating Power 30

Future Development 30

Regulating power used in a 'proactive' sense 30

Bid Aspects 31

References **32**

Overview

The regulating power market in the Nordic electricity system is part of the larger Nordic electricity market and as such it is helpful to first put this overall market and its various actors into perspective before delving into greater detail with the regulating power market. The first section thus provides a historical background for the current Nordic electricity market. This is followed by a description of the relevant actors and their roles, and the background portion concludes by detailing the Nordic electricity market structure and its various components. The rest of the report describes the Nordic regulating power market, and provides a cursory analysis of historical regulating power data.

Historical background

Nordic Electricity Market

The Nordic electricity market consists of Finland, Norway, Sweden and Denmark which deregulated and integrated their respective electricity markets during the 1990s. The integration of the markets involved the removal of barriers to cross-border trade such as border tariffs and the establishment of a common power exchange. Market design always favours some technologies over others, and the Nordic region is dominated by hydro power, nuclear, and thermal units. As a result the spot market (day-ahead) was designed accordingly, and is well-suited to their capabilities. Block bids and bidding in at least 12 hours before the operational hour gives thermal and nuclear units ample time to plan their production, which often takes time to ramp up and down. Meanwhile wind power, which only more recently has begun to play a more significant role, is not particularly well-suited to a market where the operational hour is 12-36 hours from the bidding hour. Seen in retrospect, if a market were to be designed today to incorporate current and future generation mixes with increased amounts of renewables, it is likely that this market would look somewhat different from the current Nord Pool market. The same also goes for the regulating market, where the current regulating power market is great for power plants, but does not cater to small demand.

Demand Response Timeline

In a Nordic context, demand response started to gain traction in 2001 with the first TSO report about demand response. This was followed by 2003 – 2005 demonstration of demand response involving refrigerated storage, water treatment plants, and back-up generators. Meanwhile, in 2004 the first test with demand response for electrical heating in households was carried out. In the same year the TSO organisation at the time, Nordel, released a report entitled ‘Developing Demand Response on the Nordic Electricity Market’. The following year a second TSO report about demand response was released, and the years 2006-2009 saw demonstration of demand response in houses, industry, greenhouses and offices. Projects involving demand as frequency controlled reserves were initiated in 2006 and are still underway today. Finally, in 2010 reports about dynamic tariffs, dynamic taxes and demand as regulating power were released and help set the stage for the FlexPower concept.

Relevant Actors and their Roles

Nord Pool

Nord pool manages the Nordic power exchange, which includes the physical trade in the two markets Elspot (day ahead) and Elbas (intra day), and the financial markets. Transmission lines between price areas are managed by the Spot market. More than 70% of all electricity demand in the Nordic area is currently traded on Nord Pool.

Electricity Generator

The electricity generator produces power to the electricity system. The generators bid in with their expected power production on the Nord Pool Spot market every day for the upcoming day. Examples of electricity generators in Denmark are Dong Energy, Vattenfall, and Verdo, with all three companies also participating in other aspects of the electricity market. While Dong and Vattenfall dominate the Danish market, there are also a number of smaller communally owned electricity generation units. Some generators are production balance responsible (PBR) while other generators share a PBR.

TSO

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. The Nordic TSO's own the Nord Pool power exchange. In Denmark the TSO is Energinet.dk.

TSO Associations

Before July of 2009 the TSO Association Nordel managed the synchronous area comprised of Norway, Sweden, Finland and Eastern Denmark (DK2) while UCTE managed the Central European synchronous area, including Western Denmark (DK1). As of July 2009 the 6 European TSO associations have merged into the European Network of Transmission System Operators for Electricity (ENTSO-E), covering all of Europe. The electricity system is still divided into the same synchronous areas, now called Regional Groups (RG). Eastern Denmark is a part of RG Nordic, and Western Denmark is a part of RG Continental Europe. A diagram outlining the new groupings is displayed below.

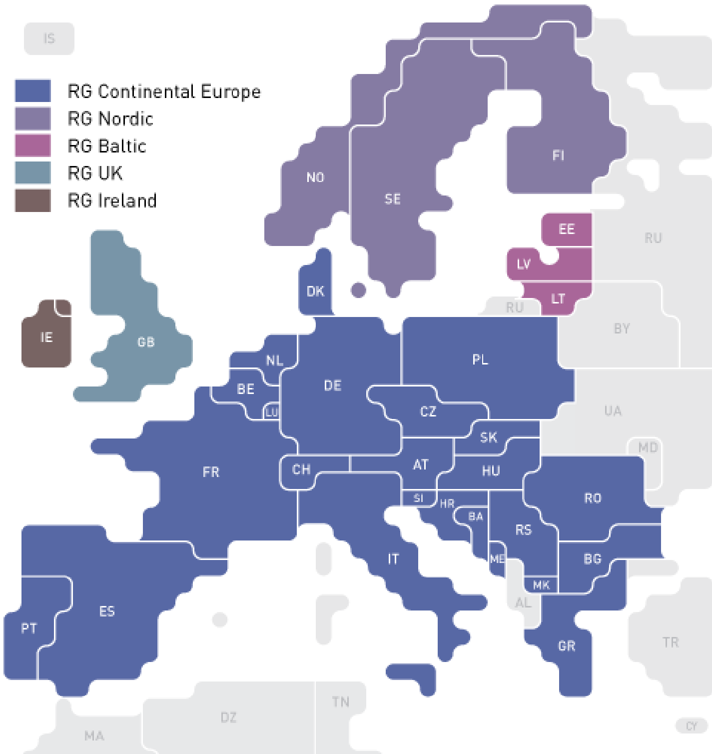


Figure 1: Diagram of the 5 Regional Groups, with their respective synchronously interconnected systems. (ENTSO-E, 2010)

DSO/Grid Company

Grid companies (distribution system operators, DSOs) operate the distribution grid and are thereby responsible for the security of supply through the delivery of power to the customers. In Denmark all grid companies are obligated to ensure that meters are installed and read at all end users. Thus it is the local grid company who is responsible if interval meters are to be installed.

Grid companies are closely regulated monopolies. They must be legally and management independent from other companies, e.g. commercial companies such as generators. The grid companies are benchmarked and the tariffs are controlled by the regulator, Energitilsynet (Danish Energy Regulatory Authority).

In Denmark, there are over 90 local grid companies, with Dong operating several companies in Eastern Denmark, SEAS-NVE, Syd Energi, and NRGI being responsible for large regions of Denmark, and a host of other companies being servicing the rest of Denmark.

Retailer

The retailer acts as a link between the power market and the consumer. The retailer communicates the consumers demand to the power market, purchases electricity from the power market and resells it to the various consumers. Electricity can be bought on the Nord Pool power exchange or directly from a local generator (bilateral trade). Some retailers are also load balance responsible (LBR), and in some cases several retailers use a common load balance responsible.

There are a number of electricity retailers in Denmark for end-users to select from. Dong, SEAS-NVE, Syd Energi, and NRGI are all active in this market as well, with other notables including Nordjysk Elhandel, EnergiMidt, ELRO, Østkraft and the independent and innovative Modstrøm.

Balance Responsible

Production Balance Responsible (PBR)

Balance Responsibles can be divided into Load Balance Responsibles (LBR), and Production Balance Responsibles (PBR). PBRs are by and large a power generation company, or several power generators joined together.

Load Balance Responsible (LBR)

LBRs are typically electricity trading companies that through the pooling of consumers bid in on the various electricity markets. The main task of a load balance responsible is to make a plan for the consumption the upcoming day. The load balance responsible must also document how the electricity has been purchased. Currently 11 companies in Denmark act as load balance responsible for demand (www.energinet.dk).

In case of imbalances (deviations from the plan) the balance responsible must buy or sell this difference from the TSO, Energinet.dk. In some situations it is costly to have imbalances, and average absolute costs of imbalances are 6.6 øre/kWh (1/1/2005 – 1/08/2010, West and East Denmark).

Regulating Power Bids

The balance responsible can be active on the regulating power market and submit bids related to up and down regulation to Energinet.dk. By pooling a number of assets together, this allows balance responsibles to meet the regulating power market's 10 MW minimum bid criteria set by energinet.dk. Currently it is mainly PBRs that submit bids to the regulating power market, but LBRs can in principle participate as well. Today electric boilers in the district heating system are the only type of Danish demand that are active in the regulating power market; however projects are underway to incorporate other technologies, for example heat pumps in the 'Fra vind til varme' project, and industrial users in Dong Energy's 'Powerhub' project (Energinet.dk, 2010).

Electricity consumer

Electricity consumers compose a broad spectrum of users, from standard household end-users with typical yearly usage of roughly 4,000 kWh (for a single family house), to large-scale industrial users with annual usage well over 1,000,000 kWh. There are roughly 50,000 Danish end-users with a yearly usage larger than 100,000 kWh and each of these end-users is equipped with an interval meter that measures the hourly electricity usage, thereby allowing them to participate in the day ahead spot market (Energinet.dk, 2010). Households do not yet have consumption that is settled according to hourly metering, however this is expected to change as there is a concerted effort to equip roughly 50% of Danish end-users with meters capable of reading remotely. Related to this, is a plan under development that will allow for small hourly measured consumers to constitute a new separate group than can utilise dynamic prices.

Interplay between actors

Figure 2 below illustrates the market actor set-up with the actors as described above. Data for the consumer's electricity consumption is recorded in the meter and sent to the DSO. After consolidation of data, they are sent to the TSO and load balance responsible. The consumer enters a contract with a retailer. Each retailer refers to a load balance responsible. The load balance responsible sends a plan for the next day's electricity demand to the TSO. The electricity can be bought from the power exchange Nord Pool, or directly from a power generator via a bilateral contract.

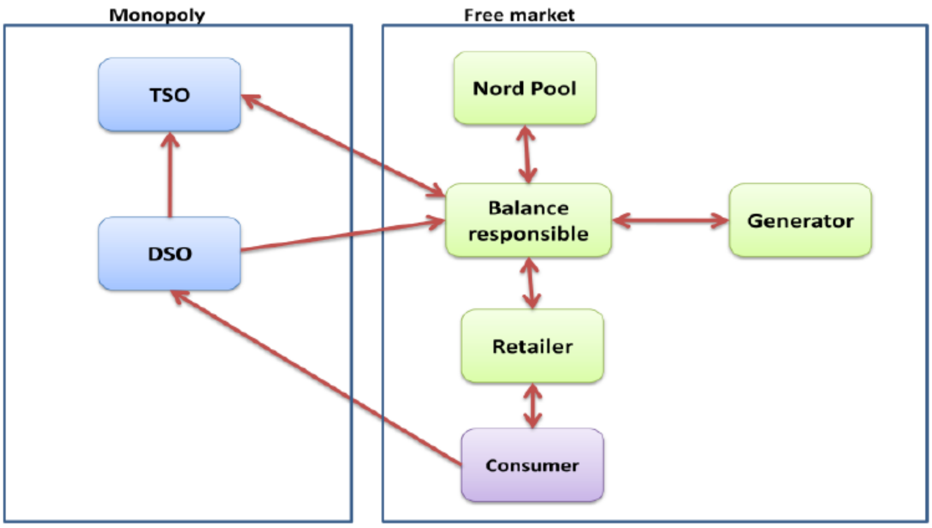


Figure 2: Simplified illustration of the interplay between market actors in the Nordic power system.

If the actual generation or consumption differs from the scheduled plan the difference is bought or sold from the TSO as imbalances.

Nordic Market Structure

The current Nordic electricity market consists of a number of specific underlying markets based on a timeline for the bidding offers. Figure 3 illustrates the major components of this market.

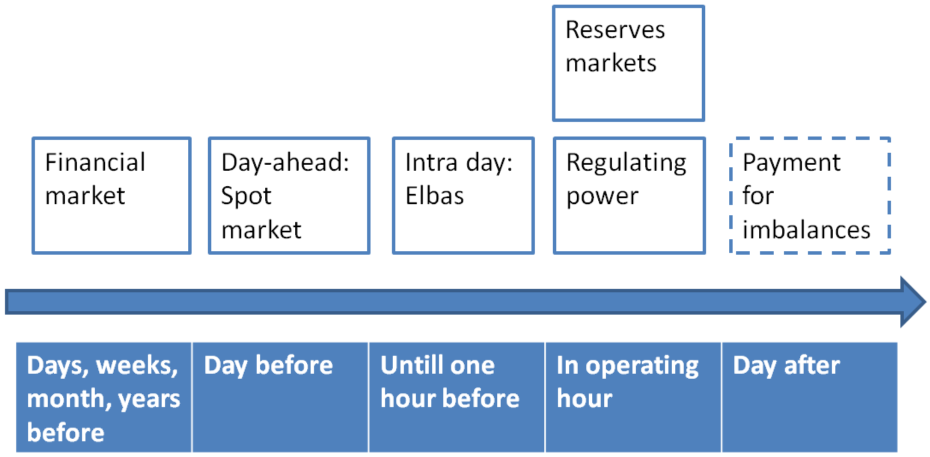


Figure 3: Different markets for different time regimes – the Nordic set-up. The reservation markets include reservation of resources for the regulating power market and other reserves

Financial market

The financial market is a commercial market, where price securing contracts are traded. The financial markets trade futures and other derivatives that are settled against future spot prices; it is possible to enter a future contract involving for example 100 MW next year. Most liquidity is related to financial contracts targeting the System Price. The System Price is an artificial price that would be the result, if no congestion exists. Financial contracts manage risks and are essential for the market participants in the absence of long-term physical contractual markets.

Day-ahead: Spot Market

The central Nordic energy market is the spot market (Nord Pool Spot) where a daily competitive auction establishes a price for each hour of the next day. The trading horizon is 12 - 36 hours ahead and is done in the context of the next day's 24 hour period. The system price and the area prices are calculated after all participants' bids have been received before gate closure at 12:00. Participants' bids consist of price and an hourly volume in a certain bidding area. Retailers bid in with expected consumption while the generators bid in with their production capacity and their associated production costs. Different types of bids exist, e.g. a bid for a specific hour or in block bids, which exist in several variations.

Determining the Spot Price

The price is determined as the intersection between the aggregated curves for demand and supply for each hour – taking the restriction imposed by transmission lines into account. Figure 4 illustrates the formation of the system price on the spot market as a price intersection between the purchase and sale of electricity.

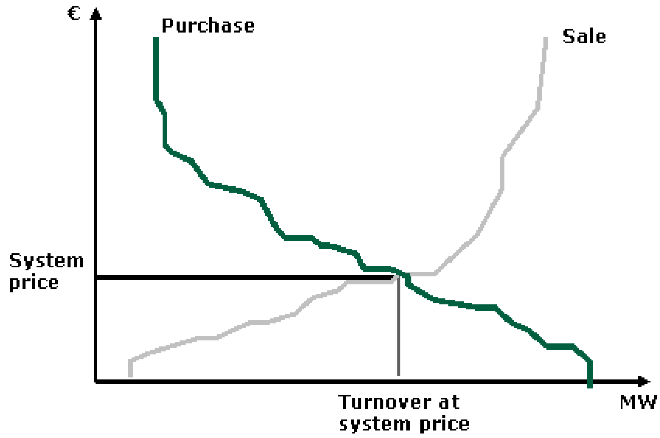


Figure 4: The formation of the system price for electricity on the Nord Pool Spot market. (www.Nord Poolspot.com)

Activation of Demand

Many activities are focusing on activation of demand in this market – in form of demand response (e.g. Johansson, 2008, Nordel Demand Response Group, 2006, Togeby and Hay, 2009). As of December 2009 negative prices were allowed in the spot market. Small generators are to a large degree active in the spot market, witnessed by the fact that as of April 2009, 75% of all CHPs below 5 MW participated in the spot market.

Bidding Areas

In order to manage grid congestions the Nordic exchange area is divided into bidding areas. The bidding areas are consistent with the geographical area of each of the TSOs. Denmark is however divided into two bidding areas, West and East (DK1 and DK2). The same goes for the Norwegian grid that is divided into three to five bidding areas.

Price Areas

Participants must make their bids according to where their production or consumption is physically located in the Nordic pricing areas. In this way the transmission capacity between the different bidding areas is implicitly auctioned via the area spot price calculation. Thus, whenever there are grid congestions, different price areas are formed. The participants' bids in the bidding areas on each side of the congestion are aggregated into supply and demand curves in the same way that the System price is calculated. In this calculation the maximum import or export over the congested line are included.

Intra Day: Elbas Market

Given that the time from fixing of the price and the plans for demand and generation in the spot market to the actual delivery hours is up to 36 hours, deviations do occur. Deviations can come from e.g. unforeseen changes in demand, tripping of generation or transmission lines, or from incomplete prognoses for wind power generation. Such deviations can be mitigated during the operational day via entering into hourly contracts in the Elbas market, where electricity can be traded from the time the spot market closes up till 45 minutes before the operating hour. However, the liquidity in this market today is limited. As of October 2010 the average traded volume for the entire Nordic area in 2010 was only 300 MW (as compared to the more than 30,000 MW average trade on the Nord Pool Spot market), however this intra day figure is trending upwards as can be seen from Figure 5 below.

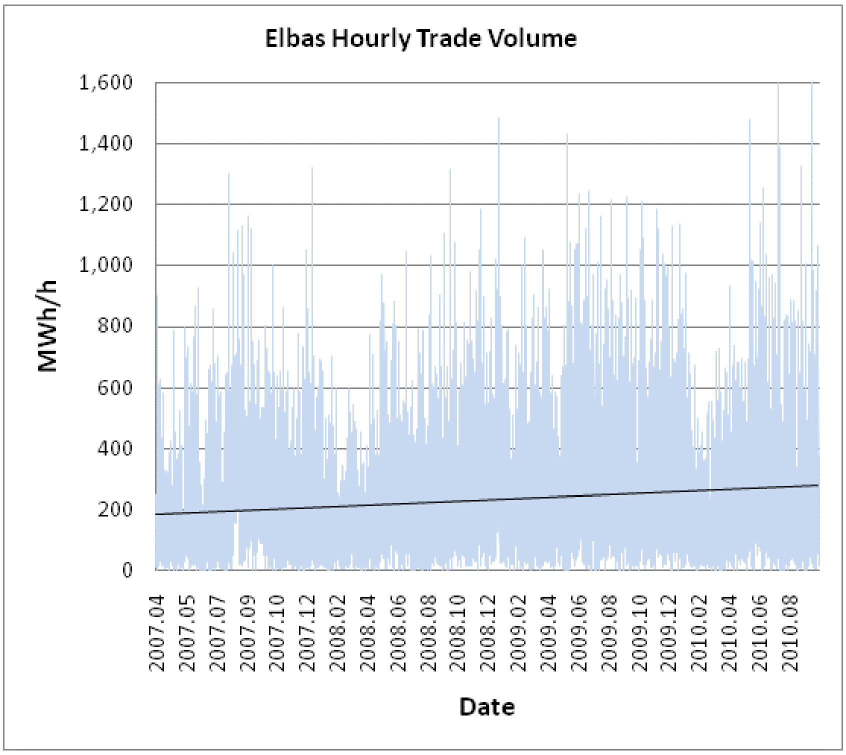


Figure 5: Elbas hourly trade from April 1st of 2007 till August 28th of 2010.

Not only does Figure 5 indicate an increasing trend in Elbas trade, it also highlights the fact that there is a great deal of variation, with some hours seeing very little trade, and others with trade over 1,600 MWh/h.

In addition to Elbas, bilateral trade is also possible until one hour before the operating hour.

Reservation Markets

As a supplement to the regulating market which will be described below, Denmark and Finland also have reservation markets.[1] Resources can receive a payment for being present in the regulating power market. It is worth noting that as the supply within this market has grown, and demand has fallen, the reservation payment is now extremely low. A similar system exists in Norway (RKOM), which is only active during the winter period.

Other Reserves

Electricity production and consumption always has to be in balance, and after the close of the Elbas market 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 order to have stability in the Nordic electricity system different criteria set by the TSO associations must be met at all times (Nordel, 2006):

- The frequency of the synchronous system must be between 49.9 and 50.1 Hz,
- The time deviation of the synchronization shall be within the range [-30s, 30s]. Time deviation is found by integrating the frequency deviation from 50 Hz,
- The requirement in RG Continental Europe that every control area has to keep its own balance,[2]
- The flow on any line must not exceed the transmission capacity at any time

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. These reserves are purchased in the market and depending on the type, can receive both a reserve payment, and an energy payment if activated. As the name would indicate, they are activated automatically in accordance with frequency deviations, but are expensive and have limited capacity.

[1] http://www.fingrid.fi/portal/in_english/services/balance_services/regulating_power_market/

[2] Western Denmark has a special requirement within the RG Continental Europe keeping its own balance in Jutland.

Imbalances

In DK2, imbalances have for quite some time been allowed to flow to and from Sweden via an AC connection. Only the total imbalance for the synchronous areas are reacted on. This allows for a reduced use of regulating power because the random imbalances in sub-areas often have opposite directions and thus cancel each other out. From June of 2008 a similar system has been introduced in DK1 with Sweden and Norway. As such, if imbalances exist in the opposite direction, and there is available capacity, these imbalances are now transported to Sweden and Norway, however in this case the imbalances are transferred via a DC connection.

LFC in DK1

It is also worth noting that there is an additional automatic reserve in DK1. While Germany and Jutland are part of the larger RG Continental Group, both areas also constitute smaller control areas, and inside the RG Continental Group each area must be able to manage its own balance. In Jutland Energinet.dk utilises Load Frequency Control (LFC), a reserve that reacts on the basis of a network controller, in response to deviations in the planned exchange between Southern Jutland and Northern Germany. The LFC maintains the planned Danish/Germany exchange and in this way it ensures that the system balance is kept in Jutland, and as a result of the system being in balance, there are no imbalances to be passed on to Germany via the AC connection.

Regulating Power Market

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. It 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.

NOIS-list

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 10MW, and the maximum is 50 MW. The Elspot price meanwhile represents the minimum price for up regulating power bids and the maximum price for down regulating power bids. 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 6.

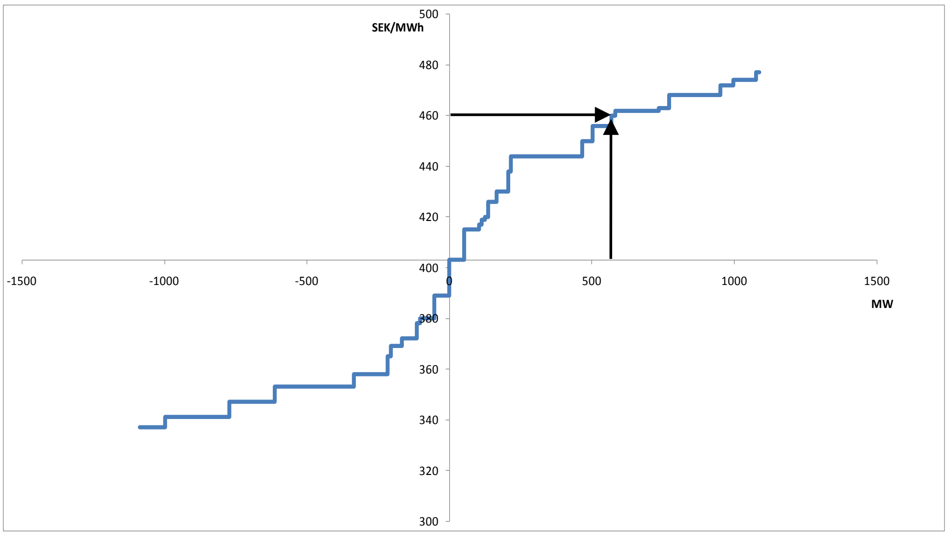


Figure 6: Example of the NOIS list, from 17.6.2009, CET 07-08. 583 MW of up regulating power was activated, corresponding to a price of 460 SEK/MWh (Data provided by SvK).

Price Settlement

As can be seen from the figure, a series of up regulating bids with activation prices less than 460 SEK/MWh were activated before the final bid at 460 SEK/MWh. This resulted in the desired cumulative total of 583 MW. However, as with the spot market, the highest activated bid price within the hour (lowest for down regulating power), becomes the regulating power price, and each activated bid receives this price.

Reservation Market

There is an interaction between the spot market and the regulating power market, and the reservation market is used to attract sufficient resources to the regulating power market. For example, with high spot prices it is so attractive to produce for the spot market that a reservation price is needed to maintain capacity for up-regulation in the regulating power market – and visa verse for low spot prices. The reservation price is established based on the amount needed by the TSO and bids from potential suppliers.

Demand Participation in Regulating Power Market

The costs of activating regulating power are passed on to the balance responsible agents after the day of operation. Today, most demand is not active in the regulating power market – and therefore must pay the cost of imbalances without e.g. benefitting from the many examples of very low prices 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 will increase to 300 MW in 2010.

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

Table 1: Definition of up and down regulation

Activation of regulating power

In describing the process of regulating power activation, a number of terms are utilised (Nordel, 2008):

- *Activation time* is defined as lead time plus ramping time
- *Lead time* is defined as the time after the order is sent by TSO until regulation is started by the bidder. In Denmark the default lead time is one minute for directly activated bids (DK2), and five minutes for bids ordered through plans (DK1).
- *Ramping time* is the time between start of regulation and start of full delivery according to the bid
- *Running time* is normally defined as the time from the start of the regulation (the agreed starting time) till the end of the hour/activation.

Figure 7 below provides an example of the activation of an up regulating power bid.

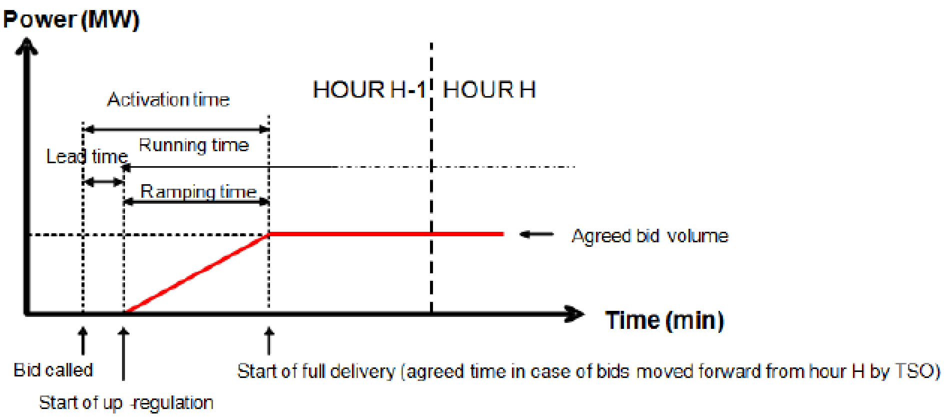


Figure 7: Example of the time schedule related to the activating of an up regulating power bid. (Nordel, 2008).

It is worth noting that in Denmark the minimum running time for a bid to count as activated in an hour (and thus utilised in calculating the regulating power price) is 10 minutes.

One-price and two-price balance settlement systems

After the operational hour, deviations between the activated load and production balance responsibles bids, and the actual amount of electricity provided/utilised, are determined. These deviations (known as imbalances) are settled with Energinet.dk on a monthly basis.

Load Balance Responsibles

For Load Balance Responsibles these imbalances are settled under a 'one-price' settlement system. It is referred to as a one price system because regardless of whether a LBR contributes to an overall system imbalance, or aids in reducing a system imbalance, the regulating power price for that hour is the settlement price for the imbalance. As a result it is actually possible for LBRs to profit from their imbalances. For example in an hour where the LBR uses more electricity than planned, but there was an excess of electricity in the system as a whole (thus resulting in down regulating power being activated) the settlement price used to pay for the excess electricity will be less than the spot price. Table 2 below depicts the price used and direction of payment under the one-price system for LBRs.

Electricity System Situation	LBR Utilised more than planned	LBR Utilised less than planned
Up-regulation (not enough electricity in the system)	Pay Regulating Power Price (higher than spot price)	Receive Regulating Power Price (higher than spot price)*
Down-regulation (excessive electricity in the system)	Pay Regulating Power Price (lower than spot price)*	Receive Regulating Power Price (lower than spot price)

Table 2: Settlement prices for the imbalance for a Load Balance Responsible under a one-price system. *Indicates situations where the LBR can profit from imbalances. (Adapted from Energinet.dk, 2010)

Production Balance Responsibles

Production Balance Responsibles on the other hand are settled under a two-price settlement system, thus not allowing them to profit from their imbalances. If a PBR's imbalance contributes to the system imbalance (a PBR for example produces more electricity than planned in an hour where the system had an excess of electricity), then the settlement price is the regulating power price (in this example a price lower than the spot price). If however the PBR's imbalance is in the opposite direction of the system imbalance, then the *spot* *price* is used as the settlement price. Table 3 below depicts the settlement situation for a PBR.

Electricity System Situation	PBR Produced more than planned	PBR Produced less than planned
Up-regulation (not enough electricity in the system)	Receive Spot Price	Pay Regulating Power Price (higher than spot price)
Down-regulation (excessive electricity in the system)	Receive Regulating Power Price (lower than spot price)	Pay Spot Price

Table 3: Settlement prices for the imbalance for a Production Balance Responsible under a two-price system.

Load Balance Responsibles are responsible for a large number of small users and have little control over what their actual usage will be. Given that LBRs are responsible for these deviations when they contribute to a system imbalance, it is understandable that they should also be able to benefit when these deviations help alleviate a system imbalance.

Production Balance Responsibles on the other hand have a high degree of control over their actual production and it has been deemed that they should therefore not be allowed to benefit from deviations. In addition, as deviations from plans are undesirable from a system view, the two-price system encourages balance responsibles to reduce their imbalances.

Limitations of current regulating market

The regulating power market is in many ways well functioning. The cost of imbalances are generally low, which is a desirable feature in an electricity market. This is among other things due to the presence of large volumes of hydro power in the Nordic system (49 GW). Hydro power is well suited to the dynamic of regulating power. However, for Denmark the access to hydro power is limited by the capacity of transmission lines to Sweden and Norway.

The current design has some drawbacks that could make the regulating power market less efficient in the future. The current market design for regulating power can be criticised for only attracting medium to large scale generation. Small-scale demands and small-scale generations are, in practice, excluded from the market.

RKOM

Nordel Demand Response Group (2006) studied the use of demand resources as operating reserves and discussed the potential improvements. Two models were discussed: A centralized model where the TSO offers capacity payment (reservation payment), and a de-centralized model only with the activation price. The Norwegian RKOM (Regulating Power Options Market) is an example of the central model with capacity payment. It is noted that for demand with a high marginal price (activation price), the capacity payment will often be the largest part for participants (because of few activations). The Nordel report mainly focuses on large and medium sized demand. For small users, it is recommended to promote hourly metering, and that end-users with electric space heating could be the first target group for consideration.

Barriers for Industrial Demand

Johansson, M. (2008) studied the barriers for industrial demand to participate in the regulating power market. Barriers were described as:

- *The 10 MW minimum bid size:* This requirement becomes additionally burdensome when coupled with the fact that demand and generation cannot be included in the same bid, and East and West Denmark are two different price areas and bids must be from same area. In the study six industrial companies used four different balance responsible agents.
- *A plan for the controllable load :* The plan must be followed and must exist with 5-minutes values. This can be difficult for demand.
- *Demand must be re-established after activation:* In some cases this may be difficult if special staff are needed for re-establishing, for example industrial production.
- *Computing the reference demand*: Since industrial demand usually does not make individual plans, it is not possible to determine a deviation from the plan.

Similar results are found in a project about regulating power from electricity demand in greenhouses (Marienlund, 2006).

Metering

Another obstacle is the current set-up that requires real-time measuring of regulation consumption 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. With tens of thousands of heat pumps, electric heating units and electric vehicles, real-time metering for each unit is unrealistic – and probably not necessary. Today the meter must only cover the controlled demand – so for a house with a heat pump used for regulating power two meters are required (for the heat pump and for the rest of the consumption).

Bidding Process

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 heavy process for smaller resources and a simpler design might attract more participants (Veen et al, 2009).

Market Aspects

Note on Data

The various analyses that follow are largely based on data provided by Energinet.dk and Nord Pool Spot. As was mentioned above, imbalances have since June 2008 been allowed to even each other out if the imbalances in DK1 are in the opposite direction of those in Sweden or Norway, and capacity exists in the DC transmission lines. In an effort to preserve an overview of the need for regulating power before imbalances are evened out, on June 1st of 2008 Energinet.dk began to maintain the statistics 'system balance – energy deficit' and 'system balance – energy surplus', with these two time series giving the amount of regulating power required in DK1. As a result, as of this date Energinet.dk also changed the statistics 'regulating power – up' and 'regulating power – down', with these statistics now reflecting the amount of regulating power that is activated within DK1, regardless of whether it is utilised to cover a need in Denmark, Norway, or Sweden.

With respect to the data series 'regulating power – up' and 'regulating power – down', Energinet.dk does not currently make this data publicly available for DK2. In this analysis this data series has thus been supplemented with data from Nord Pool Spot.

DK1 & DK2

When looking at the regulating data for DK1 and DK2 it is worth keeping in mind that DK1 has a demand that on an annual basis has been roughly 25-40% larger than DK2 (in 2008 it was greater than 40% but this difference has been diminishing, and in 2010 was at roughly 25%), and thus it can be expected that larger regulations could be required. In addition, as was indicated above, as a part of the RG Continental Group, DK1 constitutes a control area that must be able to manage its own balance.

Regulating Power: Hours

Over the last three years roughly half of the time there has been regulating power activated in DK1, however how these regulations have been dispersed has varied greatly. In 2008 there were twice as many hours with up regulation as opposed to down regulation, while in 2009 there was slightly more hours with down regulation than up. Meanwhile, while the dispersion was fairly similar in DK2, relative to DK1 there were roughly half as many hours with regulating power. These results are reflected in Figure 8 below.

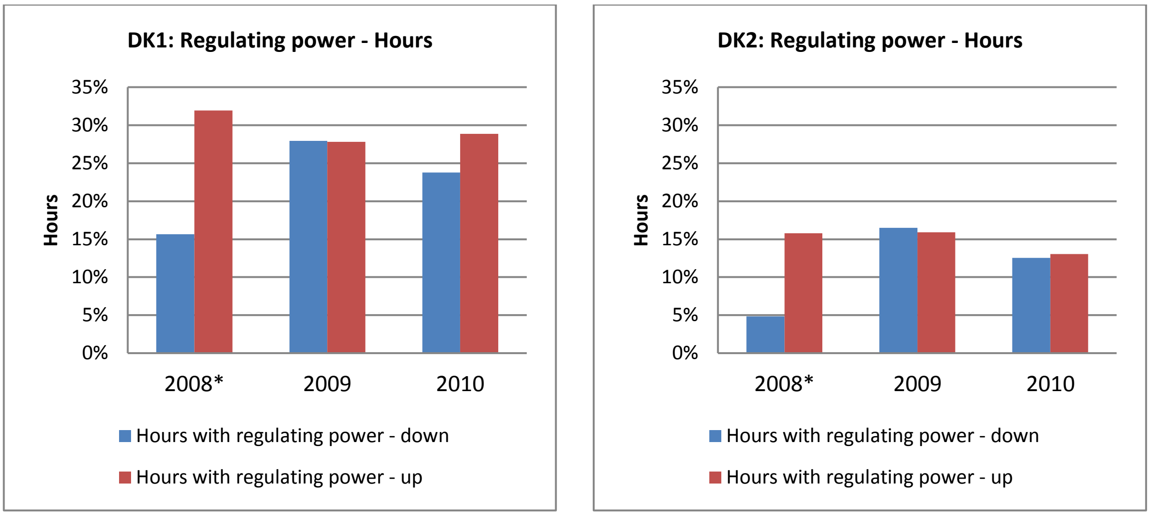


Figure 8: Percentage of total hours with regulating power activated in DK1 and DK2 from June 1st, 2008 till August 10th, 2010. *Indicates data started on June 1st.

With respect to the quantity of regulating power activated in DK1, over the last 3 years up regulating hours have averaged around 100 to 110 MW, while down regulating hours have varied a little more and averaged between roughly -65 and -80 MW. Meanwhile, down regulating figures, but particularly up regulating figures, have been lower in DK2. These figures are displayed below in Figure 9.

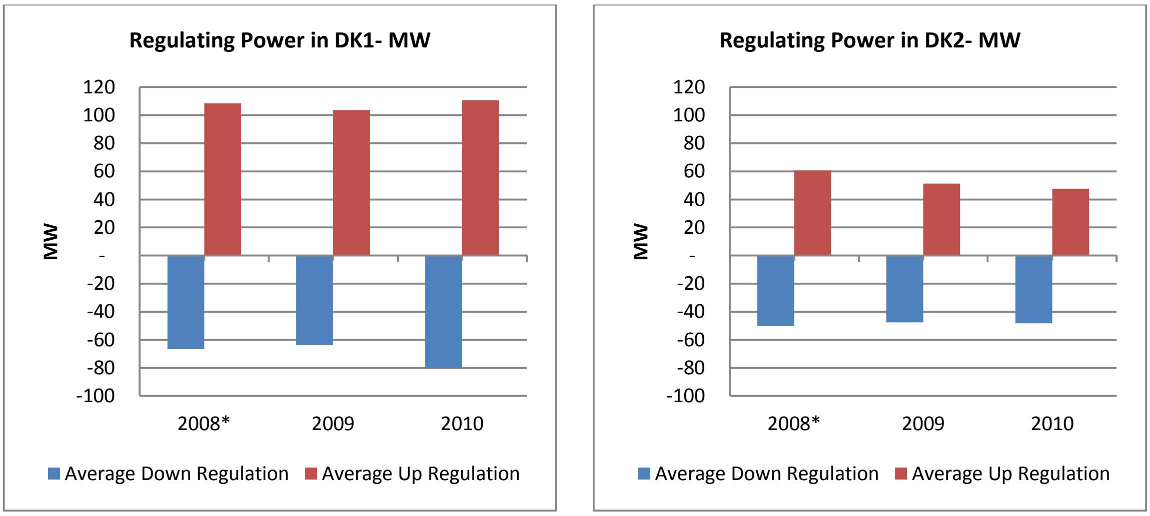


Figure 9: Average hourly volume of up and down regulating power in DK1 and DK2 from June 1st, 2008 till August 10th, 2010 in hours where regulating power was activated. *Indicates data started on June 1st.

While the above figure gives an indication of how large the up or down regulation is on average, it is also of interest to look at the % of hours that have a rather large amount of regulating power activated. Below does so, as it displays the percentage of hours that had up or down regulation in excess of 100 MW in DK1 and DK2 since June 1st of 2008.

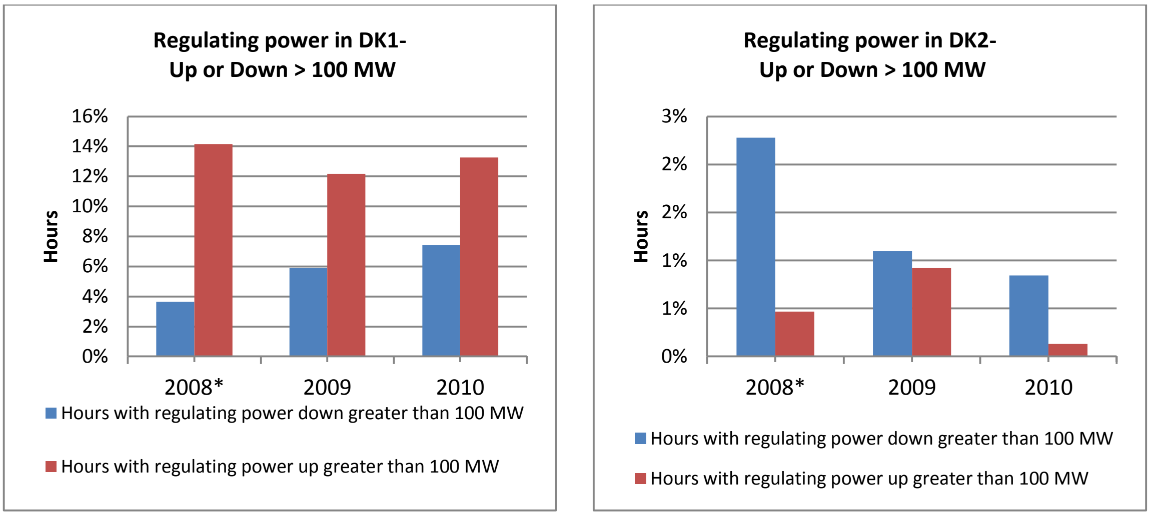


Figure 10: Percentage of total hours in DK1 and DK2 that had regulating power activations greater than 100 MW, from June 1st of 2008 till August 10th, 2010. Note that the axis for DK2 is much less than that for DK1. *Indicates data started on June 1st.

As was the case with the previous several figures, Figure 10 highlights the fact that less regulating power has been activated in DK2, with the largest discrepancy occurring when comparing up regulation. While there are very few hours with up regulation greater than 100 MW in DK2, this is the case well over 10% of the time in DK1. It should be kept in mind that this can at least be partially explained by DK1 having a larger demand.

System Balance and Import/Export

With the advent of the system balance data on June 1st of 2008 it has been possible to track the % of hours in which the system has a net surplus, deficit, or is in balance. Corresponding values for DK2 were not available at the time of writing. As can be expected, DK1 has very rarely been in perfect balance (less than 0.1% of the time), but generally speaking there has not been a large difference in the amount of time the system found itself with surplus electricity as compared to times with deficit electricity.

In terms of the average size of the system imbalance, this is displayed in Figure 11 below.

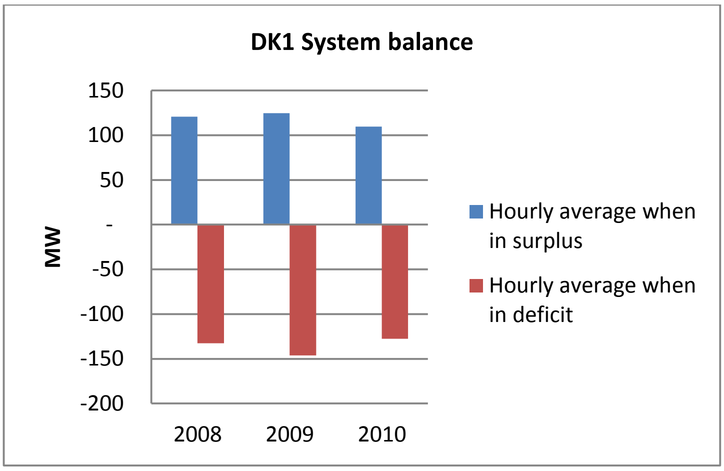


Figure 11: Average hourly size of system imbalances in DK1 for June 1st, 2008 till August 10th, 2010.

Based on the System Balance and Regulating Power figures it is also possible to determine the amount of electricity that was imported or exported to cover imbalances. This is relevant because it gives an idea of where within the system regulating power is required and provided, aspects that are of interest when considering the placement of new demand response potential. The average hourly import and export of regulating power is displayed in the figure below.

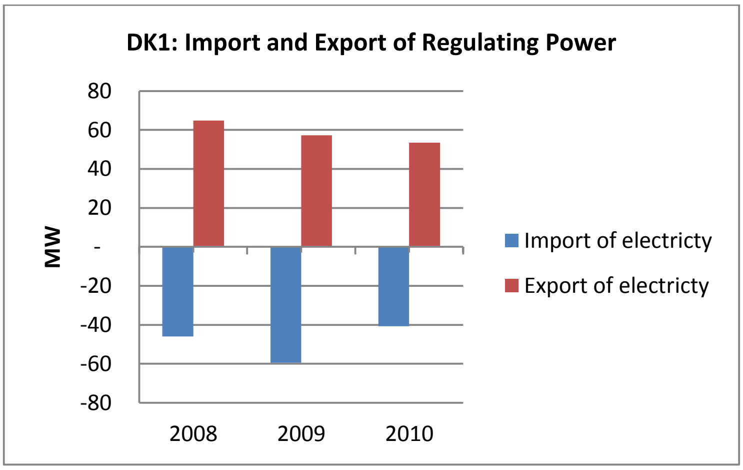


Figure 12: Average size of hourly imports and exports of regulating power for DK1 for June 1st, 2008 till August 10th, 2010.

Difference between regulating power price and spot prices

A central argument 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.

The figures below show display the average monthly spot and regulating prices in DK1 and East since January of 2005.

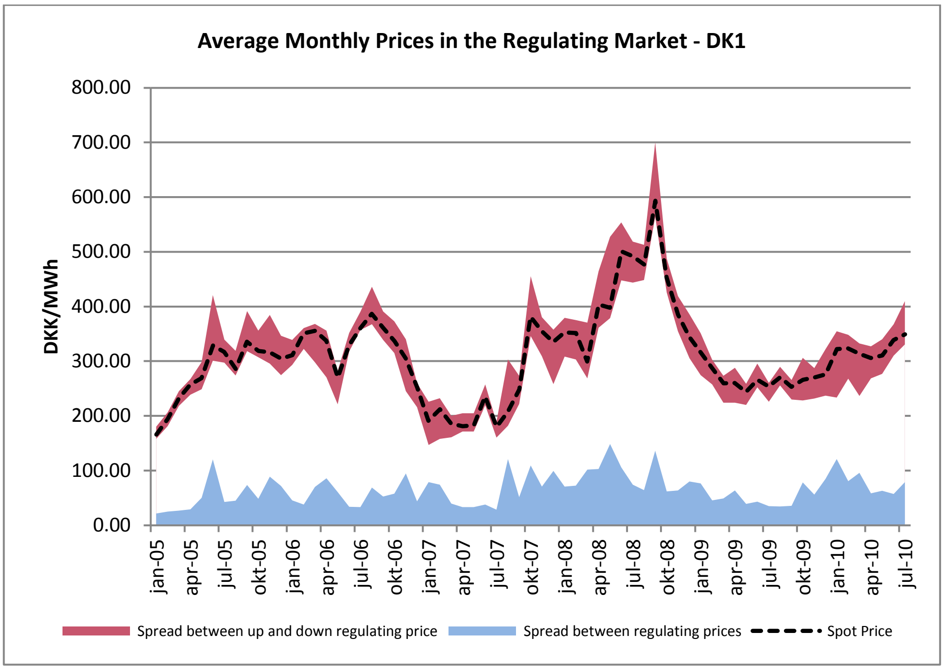


Figure 13: Average monthly spot and regulating power prices for DK 1 since January of 2005. The dotted black line is the spot price, while the red portion represents the up and down regulating prices. This spread is also displayed in blue at the bottom of the figure.

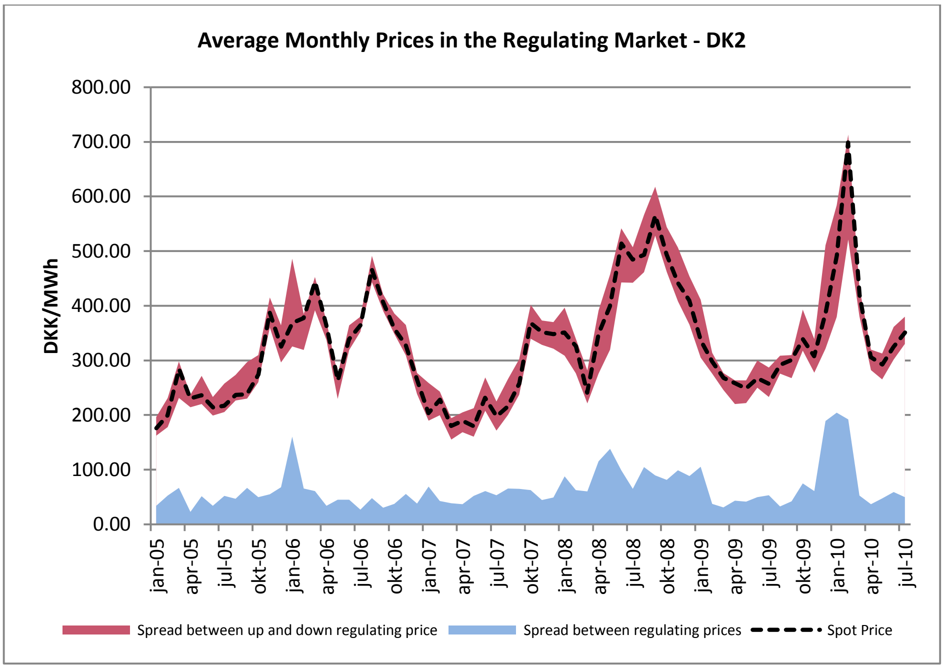


Figure 14: Average monthly spot and regulating power prices for DK 2 since January of 2005. The dotted black line is the spot price, while the red portion represents the up and down regulating prices. This spread is also displayed in blue at the bottom of the figure.

Based on the same data, for the years 2005 through to the start of August 2010, the absolute difference between the regulating power price and spot price was calculated. These results are presented below in Table 4.

DK 1	Total Hourly Average (DKK/MWh)							Max/Min	St. Dev.
Difference between:	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**Average**	**2005-'10**	**2005-2010**
Down regulation and spot price	-17.8	-32.9	-32.4	-36.7	-30.2	-47.0	-31.8	-6,566	103.6
UP regulation and spot price	35.8	24.3	32.5	53.8	23.2	30.7	33.6	7,034	151.2
Absolute Difference:	53.6	57.2	65.0	90.5	53.5	77.7	65.5	7,034	177.3
DK 2									
Difference between:	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**Average**	**2005-'10**	**2005-2010**
Down regulation and spot price	-19.6	-28.2	-22.6	-46.2	-29.1	-57.1	-32.2	-10,136	153.2
UP regulation and spot price	30.5	25.9	30.9	45.0	34.8	31.7	33.2	14,713	183.0
Absolute Difference:	50.1	54.1	53.5	91.2	63.9	88.8	65.5	14,713	234.3

Table 4: Average hourly differences in regulating power and spot prices for DK1 and DK2 for the years 2005 through August of 2010. The down and up regulating differences are averaged over all hours, as opposed to just those hours with up or down regulation. If the latter was the case, the average differences for those hours with up or down regulation would be considerably higher. The absolute difference value reflects the fact that each individual hourly average price is either an up regulating or down regulating price, not both. As such the absolute difference figures represents the average difference between the spot price and the regulating power price in any given hour (whether this be an up or down regulating price).

The figures in Table 4 indicate that for both DK1 and DK2, on average the absolute difference between the spot price and both up regulating and down regulating prices have been roughly 33 DKK/MWh. Simply put this implies that on average the absolute difference between the spot price and regulating power price has been 66 DKK/MW. 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.

Figure 15 below displays a duration curve of the hourly differences between the spot price and regulating power prices for West and East Denmark 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. For illustrative purposes the vertical axis has been limited to +/- 500 DKK/MWh, however maximum and minimum values greatly exceeded these values (see Table 5).

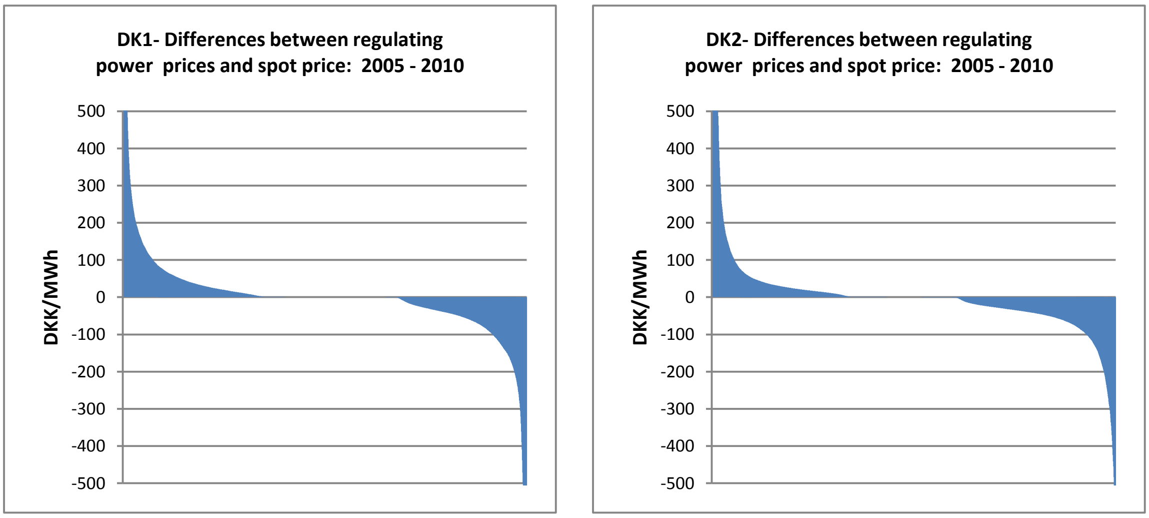


Figure 15: Historical differences between spot and regulating power prices in West and East Denmark from Jan 1st 2005 till August 10th 2010. For ease of illustration the vertical axis has been limited to +/- 500 DKK/MWh, thus affecting a total of roughly 2% of hours in both of the graphs.

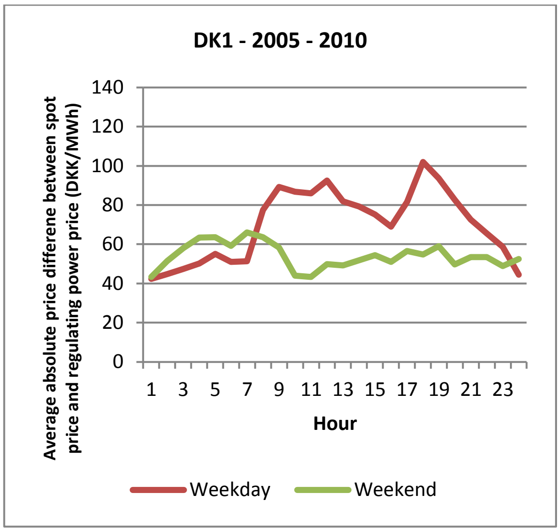
	DK1	DK2
Average Spot Price (DKK/MWh)	309	325
Hours with differences greater than 500 DKK/MWh	1.5%	1.1%
Hours with differences less than - 500 DKK/MWh	0.5%	1.0%
Hours with a difference greater than 100 DKK/MWh	7.5%	5.6%
Hours with a difference less than - 100 DKK/MWh	8.5%	7.3%
Hours with a difference 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 5: Historical differences between spot and regulating power prices in West and East Denmark from Jan 1st 2005 till August 10th 2010.

Figure 15 and the accompanying table highlight a number of relevant aspects. Firstly, in roughly ¼ to ⅓ of the hours the regulating power price has deviated very little from the spot price. However, when there have been deviations they have been rather sizeable. This is reflected by the fact that 12 – 15% of the hours saw deviations greater than +/- 100 DKK/MWh, with well over half of these occurring in down regulating power hours - namely those hours with low (or negative) regulating power prices, and as such those that are particularly interesting for EV owners. Lastly, it is interesting to note that the tips at either end of the duration curve are very steep, and as such while rare in number, those hours with large variations are extremely large indeed.

The large dispersion of the data which is reflected in Figure 15 and Table 5, and by the fact that there is a significant difference between the average and median values and a large standard deviation, means that if consumption is placed in the correct hours the difference between the spot price and regulating price will on average be much higher than 66 DKK/MWh. For example, the average absolute price difference for the 50% of hours with the largest price difference is over 120 DKK/MWh.

The analysis above looks solely at the hourly average and does not take into consideration time of day, or whether it is a weekday or weekend. This is particularly relevant for electric vehicles, as it is foreseen that they will charge during the night and weekends where existing electricity demand is lower. Figure 16 below illustrates the historical hourly average difference between spot prices and regulating power prices when both the time of day and week have been taken into consideration.



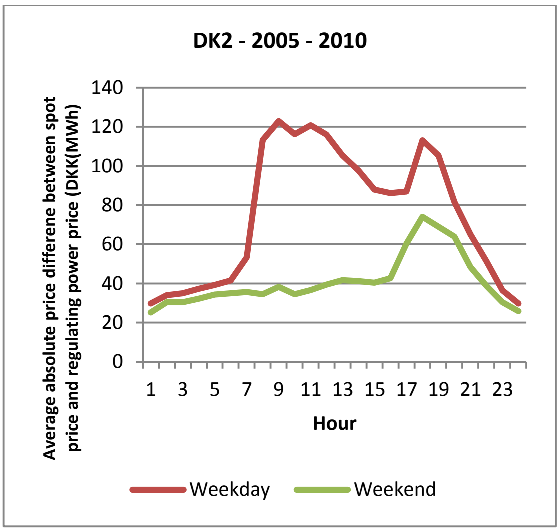
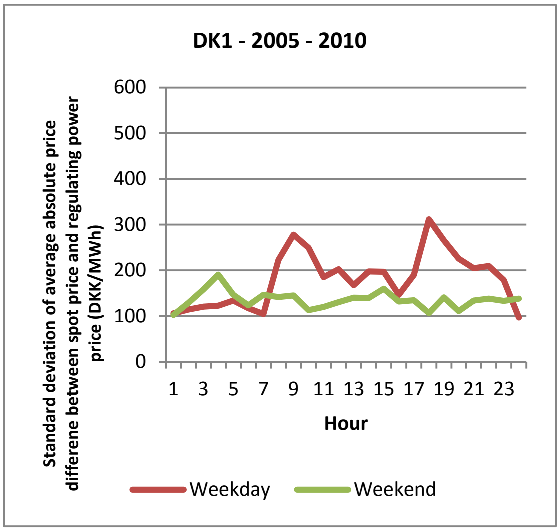


Figure 16: Average hourly absolute differences between the spot price and regulating power price based on the time of day and week for DK1 and DK2. The red line indicates the hourly average for weekdays and the green the hourly average for weekends.

The figure indicates that generally speaking the price difference is lowest in the hours from 23:00 till 06:00. In DK1 the hourly absolute average difference on weekdays has been in the range of 40-55 DKK/MWh, and slightly higher on Weekends. In DK2 the price difference has been lower, as it averaged roughly 25 – 40 DKK/MWh during these lower demand hours.

In looking at the standard deviation of the data when taking into consideration the time of day and week (see Figure 17 below), it is also considerably lower in off-peak hours, but it is still relatively high, thus indicating that even in off-peak times there are a number of hours with large differences between the spot price and regulating power price. It is interesting to note the greater volatility in DK2 relative to DK1, and also the very large standard deviations found during weekday hours.



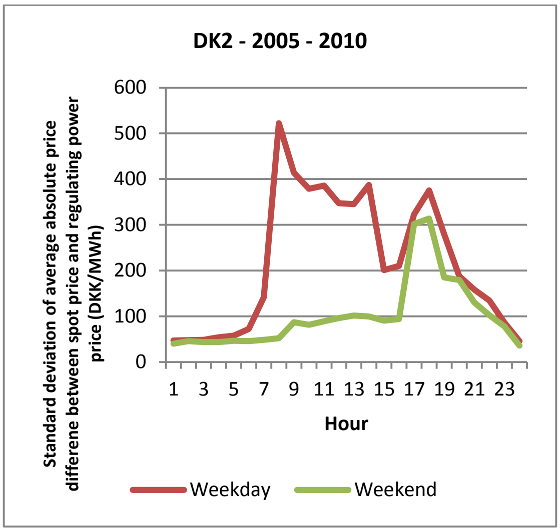


Figure 17: Standard deviation of the average absolute price differences between spot prices and regulating power prices for DK1 and DK2, based on time of day and week.

While the aggregate standard deviation figures in Figure 17 fairly clearly depict peaks in the morning, as well as the early evening, caution should be taken in assuming that each year will have figures that result in a similar structure. In fact when graphs were made for the individual years, quite different tendencies were observed from year to year.

Taking all the above into consideration it can be concluded that:

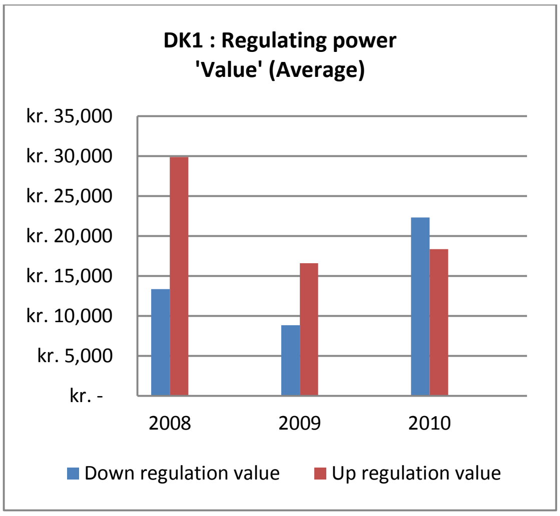
- Aggregated over all hours since 2005, the average absolute difference between the spot price and power regulating price has been roughly 66 DKK/MWh.
- If we for example take a look at it from an electric vehicle perspective, it is more relevant to look at weekends and the hours from 23:00 till 06:00 on weekdays, as these represent desirable charging times. These off-peak hours have an absolute hourly average difference ranging from 25-55 DDK/MWh.
- Both data sets contain a great deal of variance with very high standard deviations, thus indicating that there are a considerable number of hours with price differences much greater than the aforementioned hourly average, and therefore a great many hours where it would likely be significantly more profitable to participate in the regulating power market as opposed to the spot market.

Difference between regulating power price and spot prices: Value

While the above section looked at the difference between spot prices and regulating power prices, it is also interesting to look at what the additional value of this price difference has been. The figure below displays the additional value of activated regulating power, with additional value being defined as the quantity of regulating power activated multiplied by the difference between the spot and regulating power price.

It is important to note that this 'value' simply reflects the difference in the value of electricity purchased in the spot market and regulating power market in each hour. In this respect, it is not necessarily a reflection of how much could be earned from participating in the regulating power market. For example, in an hour (DK2 17.12.2009), with an extremely high spot price (10,135 DKK/MWh), a fairly normal down regulating price (282 DKK/MWh), and down regulation (69 MW) the resulting down regulation 'value' (700,000 DKK) is extremely large. Thus the large 'value' reflects the difference for an actor that could purchase electricity at the low regulating power price, and sell it at the extremely high spot price. In such a circumstance a flexible user bound to the hourly spot price would likely react on the published spot prices and reduce their consumption.

Figure 18 below displays this data on an hourly basis.



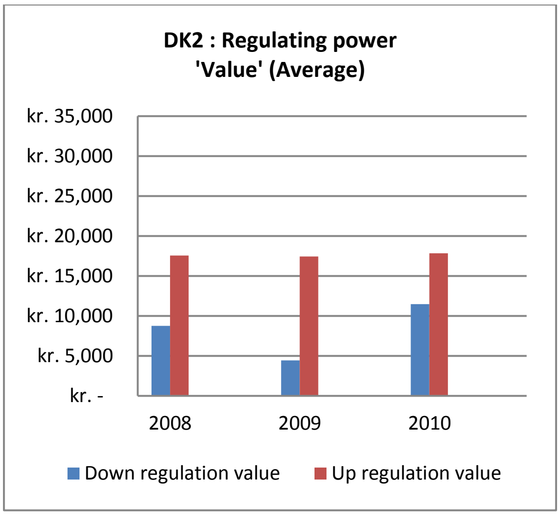


Figure 18: Hourly value of regulating power with respect to spot price. Derived by multiplying the amount of activated up or down regulating power in each hour by the difference between the spot price and regulating power price. These figures were then averaged and therefore reflect the averages from hours where there was up or down regulation. 2008 is based on data from June 1st till the end of the year, 2009 the entire year, and 2010 is through to August 20th.

Duration of Regulating Power

Another important aspect for potential FlexPower users is the length of time up or down regulation may last. This is particularly relevant for technologies that postpone the time of use, as any reduction in current electricity usage will require increased usage at a later point. FlexPower will not be very effective if this usage is simply transferred to a time when regulating power is still required. When looking at historical regulating power in DK1, data from mid 2008 till August of 2010 indicates that on average, periods with up regulation have lasted a roughly 4 to 4.5 hours, while similar data for down regulation indicates average periods of 3 to 4 hours. It should be noted that these findings are based on hourly data, and as such represent upper limits. An hour for example could have up regulation in the first portion, a period of no regulation, and then up regulation in the latter portion of the hour, but the above data would simply reflect the fact that up regulation occurred within the hour. In addition, the hourly data is based on all regulating power activated within the hour, not individual bids, and therefore the average duration of individual bids would also be lower than the figures outlined. As a result, the data indicates that on average regulating power will not be activated for periods of more than 4 hours at a time, and as such should ease concerns that FlexPower users will not have the ability to shift their consumption to a more favourable time

Future Development

With the intense focus on climate challenges, renewable energy becomes an important tool for reducing emissions from fossil fuels. In Denmark, 800 MW of new offshore wind turbines will be built by 2012. When wind power capacity is expanded, more regulating power will likely be needed due to the limited or imperfect predictability of wind power. Togeby et al (2009) describes the structure of prognoses error in wind power forecasts. It was found that the largest errors occur when medium wind speeds are expected.

More wind power is expected to increase the need for regulating power, and thus, more focus will be in the regulating power market. The focus will also be on including more participants in the regulating power market.

Regulating power used in a ’proactive’ sense

In its recently published ‘Udvikling af rammer for regulerkraft’ Energinet.dk described its activation of balancing tools as a *proactive reaction* to a future anticipated imbalance (Energinet.dk). Based on updated effect plans, newer information, various prognoses and measuring tools, Energinet.dk anticipates potential deviations from the original operating plan, and activates regulating power accordingly, that is before the deviation from the plan occurs. Regulating power has traditionally been regarded as a necessary response to deviations from the plan, and as such describing regulating power as *proactive* perhaps represents a shift in how regulating power is viewed. If so, this may signal a willingness to incorporate other forms of regulating power such as those proposed in FlexPower.

Bid Aspects

Bid Size

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 from December of 2008, Nordel also opened the door to smaller bid sizes in the future. Particularly as more of the Nordic countries move to automation of bids (Denmark did so in 2008, Sweden has introduced it, and Norway has a project to address automation), this will allow for smaller bid sizes, something that the report indicates would help to promote demand-side bidding. (Nordel, 2008)

Bid Type

Another topic that the above mentioned 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. The idea being that these faster bids should not receive any preferential treatment on the NOIS list when used for normal balance regulation, but could be utilised in special situations and thus taken out of order. Related to this, the report also suggested that slower bids could be placed on the NOIS list and also utilised as a special regulation, however in this case only when all normal bids have been used.

References

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

ENTSO-E (2010): https://www.entsoe.eu/system-operations/regional-groups/

Marienlund, L. (2006): Priselastisk elforbrug som reservekraft i gartnerierhvervet. Dansk Gartneri.

Nordel (2006): Nordic Grid Code, System operation agreement

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

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

Togeby, M., Hay, C. (2009): Prisfølsomt elforbrug i husholdninger (Demand response in households). With DI – Energibranchen, SYDENERGI a.m.b.a. SEAS/NVE a.m.b.a. Siemens A/S Danfoss A/S.

Togeby, M. (ed.), J. Werling, J. Hethey, L. Bregnbæk, A. Kofoed-Wiuff, H. H. Lindboe, Kim Mygind, J. Ahmt, A. Filippidis, P. Meibom. P. E. Morthorst (2009): Bedre integration af vind Analyse af elpatronloven, treledstariffen for mindre kraft-varmeanlæg, afgifter og andre væsentlige rammebetingelser. (Integration of increasing amounts of renewable energy into the electricity system. For the Danish Energy Agency and the Danish Ministry of Taxation)

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