International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

December 2012	Issue 13	Volume 4	Number 4	Pages 144-148

HOW DEMAND SIDE CAN PROVIDE OPERATIONAL FLEXIBILITY TO POWER SYSTEM THROUGH A HOLISTIC AGGREGATOR CONCEPT

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Abstract- More dynamics in the power systems leads to an increasing need for operational flexibility. Integration of non dispatchable power generation and changes in consumption patterns due to implementation of heat pumps and electric vehicles are examples of drivers behind this development. Traditionally such changes have been met by capacity expansions through central power generation facilities and grid enforcements. Utilizing flexibility options at the demand side is an alternative approach. Currently there exists an unexploited potential for flexibility at demand side, and implementation of Smart Grids technologies will increase this potential further through demand response, distributed dispatchable generation and distributed storage. Existing market regime already supports business opportunities for flexibility, but demand side options rarely have access to such markets. This paper describes benefits from flexibility in different perspectives. Current Norwegian power markets are described with the focus on business opportunities for flexible production and consumption. Although several markets and contract types exist where flexibility can make profit, barriers prevent demand side participation. A demand side flexibility aggregator concept is proposed to overcome these obstacles and increase profitability for all parts of the value chain. Profitability is improved through a holistic approach: on one side all flexible demand side technologies are included and on the other side revenues are considered from all available markets and agreements.

Keywords: Demand side Flexibility, Smart Grid, Aggregator, Power Market Design.

I. INTRODUCTION

The power systems all around the world are facing challenges because of increasing amount of dynamics. There are several drivers behind this development. One major driver is the energy and climate policy aiming for reduced greenhouse gas emissions, more renewable energy generation and increased efficiency in the energy use. All these targets have impact on the operation of the power systems leading to increased need for flexibility for balancing and reserves purposes.

Many of the renewable energy sources, like solar PV (photo voltaic) and wind turbines, are both non dispatchable and difficult to forecast [1]. Unpredicted and in particular rapid changes in wind speeds or solar radiation increase the complexity in balancing supply and demand and in keeping the grid operation within safe limits. Extra capacity for reserves is needed to maintain such a system.

The transition from fossil fuelled energy consumption to consumption delivered by renewable sources is leading to increased electric demand for instance in heat pumps and in charging of batteries in plug in electric and hybrid vehicles. Combined with increased number of electric appliances this gives more demand in general, but also higher peaks and more dynamics. In addition to more complex matching of supply and demand, these changes create need for capacity expansions and more complexity in the operation of the distribution grids.

Increased dynamics have traditionally been met by capacity expansions in the central power generation system and by building more power lines in the transmission and distribution grid. An alternative approach is utilization of flexibility options at the demand side. Even today there exists a potential for demand side flexibility, but the lack of incentives and technical and administrative arrangements prevent such utilization. Further increase in this flexibility potential is expected through implementation of Smart Grid technologies constituting of advanced metering infrastructure, smart appliances and intelligent infrastructure in buildings, technologies for dispatchable distributed generation and technologies for distributed storage. Such a development will create more flexible consumers and even "prosumers" that may produce part of own energy demand or even sell surplus energy.

Many studies analyse how flexibility options may be used in the existing market structure. Several of these focus on one or a few specific technologies from single consumers and used against one specific driver. The [2], [3] and [4] are examples of this, where for instance [2] is analysing demand response from electric water heaters based on spot prices and time of day network tariff.

The concept of aggregation is outlined in [5]. The paper analyses the demand dispatch concept at a high level describing how customer-owned loads, generation, and storage resources can operate collectively as a complement to traditional power plants and create a new operating paradigm. The paper lists potential benefits from the demand dispatch concept, in particular seen from the grid perspective, and concludes that with 10% consumer participation the nationwide (US) reduced cost amounts to several billion dollars per year. However, the report states, positive examples of demand dispatch in operation are few.

The [6] models how an aggregator can cluster consumers into groups with a known demand response function. Flexibility volumes are bid to the day ahead market, with the objective to maximize the aggregator's profit. The paper covers loads only. In [7] markets for energy, regulation and spinning reserves are modeled, in the perspective of how V2G resources can contribute.

The literature review shows that there exists a lot of work in this field. However most of the work focus on fragments of the problem area, often limited to specific technologies (e.g. loads only) and a few selected incentives/markets (e.g. a given spot price).

In this paper a holistic approach is described containing on one side all possible demand side technologies and on the other all possible market opportunities. Such an approach will increase the potential volumes, make existing markets accessible for demand side participation and probably increase the profitability for all involved actors in this value chain, through multiple revenue sources.

The rest of the paper is organized as follows: Section 2 lists the benefits from flexibility. An overview of the Norwegian power market is given in section 3 with the focus on operational flexibility. Section 4 describes barriers for demand side participation and introduces the demand side aggregator concept.

II. BENEFITS FROM DEMAND SIDE FLEXIBILITY

As highlighted in the introduction there are growing needs for flexibility in the power system. Smart Grid technologies may contribute to meeting these flexibility needs and create benefits at different levels. Benefits from Smart Grid technologies in general are described in [8], while [5] describes benefits from flexibility in particular.

Table 1 shows a synthesized list of benefits based on these papers among others and grouped into 4 different perspectives: 1) The power generation system, 2) the transmission and distribution grid, 3) the power markets and 4) the society in general.

Table 1. The synthesized list of benefits

Power generation	Deferred investments in peak generation capacity Less land use/ reduced natural impact Reduced need to run peak generation Optimized operation of power plants (increased possibility to run at best efficiency levels) Less need for reserves Increased ability to integrate intermittent renewable generation
Power transmission and distribution	Deferred investments in new power lines and equipment Less land use/ reduced natural impact Improved reliability (fewer outages, less customer impact, shorter outages) Optimized grid operation Improved maintenance Improved operator knowledge of actual situation Improved control options for handling voltage problems and congestion Reduced power losses Possibility to run in islanding mode
Power markets	More efficient markets, reduced market inefficiency Increased price elasticity, less volatile prices (lower price peaks) New technologies participating actively, increase in volumes New market players, reduced market power opportunities
Society in general	Increased possibility to fulfill political goals Increased integration of renewable generation Increased integration of electrical vehicles Reduction in greenhouse gas emissions Less land use/ reduced natural impact

III. THE NORWEGIAN POWER MARKET

The Norwegian power sector was deregulated in 1991 by introduction of market economic principles for power production and sales. Later the other Nordic countries Sweden, Denmark and Finland followed and a joint Nordic power market was developed. NordPool, the Nordic Power Exchange, was established to operate markets for trading of day ahead contracts (Elspot) and financial instruments. In principal the Norwegian power market may be divided into two levels: The wholesale market and the retail market. General descriptions of the Nordic wholesale power market are for instance given in [9] and [10]. This section gives a brief description with the focus on flexibility.

The overall timeline in the wholesale market may be split into 4 phases:

1) Reservation markets and financial trading (> 36 hours before operation hour)
2) Planning (Elspot (12-36 hours before operation) and Elbas (> 1 hour before operation hour))
3) Operation (Tertiary (< 15 minutes before operation minute), Secondary (< 1 minute) and Primary Reserves (< 0.5 minute)
4) Imbalance settlement (after operation day).

Figure 1 shows the sequence of the markets.

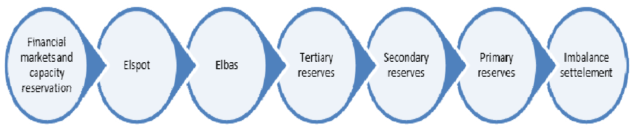

Figure 1. Sequence of Norwegian power markets

A. Capacity Reservation

The markets are run by the TSO to allocate reserve resources to be used in later phases. In general participants that get such allocations are paid a reservation price according to the reserved volume (similar to an option) and another price when activated. Statnett, the Norwegian TSO, currently runs the following reservation markets relevant in our context:

- RKOM: Regulating power options market to attract sufficient capacity to the regulating power market (tertiary reserves).
- ENOP: Energy options for consumption. These are agreements with industrial companies to cut consumption if needed.
- FNR/FDR: Primary reserves automatically responding to changes in frequency, covering normal operation (FNR) and disturbed operation (FDR). Both production and consumption may be reserved.

The Elspot market is a day ahead market, where the market participants before gate closure submit their bids for each hour the subsequent day. Each bid consist of a bid curve (pairs of prices and volumes) for each hour and each area that the participant is trading in. Additional bid formats for block bids and flexible bids exist. The participants use the Elspot market to plan their power portfolio into balance. NordPool Spot clears the market where supply and demand balance constrained by transmission capacity between areas.

Bidding into the Elspot market is done 12-36 hours before the operations hour. When approaching the operation, preconditions for the bid may have changed, since forecasted values are getting more and more certain the closer the operational hour. In order to regain the balance, the market participants may use Elbas (electricity balance adjustment). Trading in Elbas opens after the Elspot prices are published and closes for each hour 1 hour before the operation.

The tertiary reserves are handled in the regulating power market covering reserves that can be activated within 15 minutes when called upon. Regulating power market bids are used to meet imbalances between production and consumption and to handle congestions that are not taken care of in the Elspot market.

Primary reserves are automatic reserves reacting continuously to changes in frequency (MW/Hz). A deviation in frequency implies an automatic adjustment in generation, and the production will deviate from the plan. In order to regain a situation close to the original plans the secondary reserves may be called upon. Such reserves must be activated within 1 minute and release the primary reserves to be available for new imbalances.

When the operations phase is passed the imbalance settlement phase is entered. Each market participant calculates the deviation between planned and real balance, and these imbalances are paid according to imbalance settlement rules based on prices in the regulating power market.

Most of the consumers (households and small businesses) do not buy their electricity directly in the wholesale market, but from the retail market. Each consumer in the retail market must have two different contracts: a grid contract with a DSO and a supply contract with a retailer.

The DSO is the grid company that the consumer is physically connected to. The consumer can normally not select contract type this is given by the type of consumer (household, business etc.) and delivery site (voltage level, fuse size etc.).

Consumers with a yearly consumption below 100.000 kWh normally have a two-part tariff (fixed fee (NOK/year) and volume fee (NOK/kWh), while customers above this limit have a three-part tariff, also including a peak element fee with a cost based on the highest consumption (NOK/kWh) for a given period, for instance a month. The cost for each tariff part is published in advance by the DSO.

Other special arrangements also exist. One relevant in our context is disconnectable consumption that the DSO activates when facing problems in the grid operation. In order to enter such an agreement, the delivery site must have installed capacity (kW) above a certain limit, the consumption must be hourly metered and the disconnection process is required to be performed remotely by the DSO. The economic compensation basically consists of two parts: a reservation fee and compensation when disconnected.

Each consumer can freely choose which retailer to enter into a supply contract with and what type of contract. The supply part of the electricity sector is organized based on free competition, and many different contract types and products exist. However the most popular types are Elspot based contracts, variable contracts and fixed price contracts. In 2010 55% of the Norwegian households had Elspot based contracts, 40% had variable price contracts, while 5% had fixed price contracts.

Elspot based contracts are contracts with prices directly connected to the Elspot prices. A mark-up is added, based on a fixed amount (NOK/kWh) or a fixed fee (NOK/month). Since the consumption for households and small businesses are metered only in intervals there is currently no direct link between the hourly prices and the hourly consumption. This is normally handled by constructing hourly consumption values through standard profiles. However an important point here is the total absence of incentive to move consumption away from peak hours.

In addition to these standard supply contract types other innovative types have been tested and are being offered to the market. Examples are contracts with variable price but with a guaranteed maximum price or contracts with a fixed price and volume but with the possibility to sell back if the prices turn high.

NVE (The Norwegian Water Resources and Energy Directorate), the regulator in the Norwegian power sector, has decided that all customers (including those with yearly consumption less than 100.000 kWh/year) are going to get installed advanced metering infrastructure (AMI) within 2017. Implementation of AMI includes smart meters that can register electricity consumption down to 15 minutes intervals and electronically send the values to the DSO. Communication is required to be two-ways, meaning that information also may be sent from the DSO to the smart meter. Such information may be prices or other relevant data. Deployment of AMI is expected to lead to development of new price regimes and new services in the power sector.

IV. THE ROLE OF A DEMAND SIDE FLEXIBILITY AGGREGATOR

As we have seen above, there exists a diversity of market opportunities for flexibility in the power market, especially in the wholesale market. In order to utilize the existing markets and agreements some basic preconditions must be fulfilled:

- The volumes must be above a minimum size
- The volumes must be guaranteed to be available when needed
- The actions must have a minimum duration
- The flexibility must be activated within a given time frame
- The activation must be done automatically/electronically

Such requirements imply that only big, flexible generators and some industrial consumers are potential participants. Flexibility that in fact exists in other segments is not able to take part. Other segments may be large public and commercial buildings, smaller industrial companies and perhaps even households.

One potential way of opening up for participation of such volumes is through the role of an aggregator. An aggregator is a link between the customers (with flexibility) and the market, aggregating volumes to be big enough and performing the necessary actions and services to plan, trade and control the equipment. By such an approach the flexibility may be activated without involving the consumer, perhaps even without the consumer noticing the actions at all.

The aggregator then will have an important role in enabling the flexibility as a resource to gain the benefits for all parts of the value chain. The aggregator may be viewed as a portfolio manager with an underlying portfolio of flexible energy resources and with an overlying portfolio of contracts and market opportunities, including both organized market places and bilateral agreements. The figure below illustrates this concept.

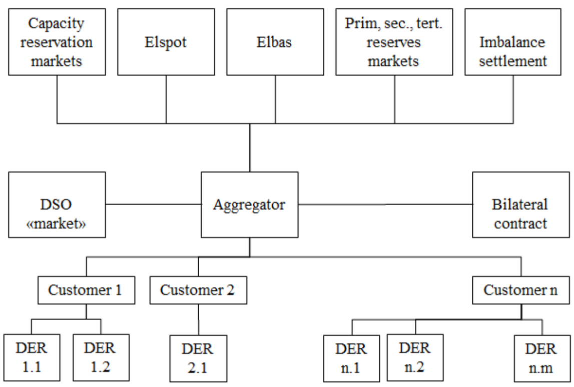

Figure 2. The demand side flexibility aggregator concept

The figure also illustrates that the concept opens for multiple revenue sources for the aggregator. This may in turn increase profitability, which is a key challenge for Smart Grid projects today. The aggregator's decision problem will be to optimize the underlying available flexibility technologies against the overlying portfolio of available trading instruments to maximize profits.

How these profits are going to be shared between the aggregator and each of the involved customers is another question to be decided. Business models and contract types must be designed to create efficient profit and risk sharing. Another basic challenge that must be solved is how the aggregator can guarantee that the agreed flexibility volumes actually are available when called upon. This uncertainty must be handled properly.

Finally this concept involves a comprehensive amount of communication technology to check status, send control signals and to meter the responses. In order to prevent vulnerability robust technical solutions is a prerequisite.

V. CONCLUSIONS

This paper describes the demand side flexibility aggregator concept which may contribute to meeting the power systems' increasing need for operational flexibility. The unexploited existing potential for demand side flexibility is expected to further increase in the coming years through technology development and implementation of smart meters and Smart Grids. In a Norwegian perspective the paper describes existing markets, contract types and agreements as revenue sources for flexibility. Despite presence of such markets demand side participation is prevented.

Technical, administrative and commercial barriers are reasons for this. The demand side flexibility aggregator concept may close the gap between the available potential and the power systems' need and create profitability. Aggregation of volumes, utilization of multiple revenue sources and service provision to the flexible consumers and prosumers are key success factors. However technical, administrative and commercial issues still need to be solved.

NOMENCLATURES

AMI	Advanced metering infrastructure
DER	Distributed energy resources
DG	Distributed generation
DR	Demand response
DS	Distributed storage
DSM	Demand side management
DSO	Distribution system operator
EV	Electric vehicle
PX	Power exchange
PV	Photo voltaic
TSO	Transmission system operator
V2G	Vehicle to grid

ACKNOWLEDGEMENTS

The author would like to thank the Norwegian Research Council for funding of the Ph.D. project through the innovation project "Manage Smart in Smart Grids". In addition the author is grateful for the support and input from the supervisor, Professor Asgeir Tomasgard and the project group in "Manage Smart in Smart Grids", headed by Professor Bernt Bremdal.

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BIOGRAPHY

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