Demand Response – A Nordic Perspective

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Definitions

Due to the efforts in climate change mitigation, there is a strong global will to increase the amount of low emission energy sources, especially wind and solar power, to the power system. In addition to climate change, other environmental issues, the opening of the electricity markets, increased reliability requirements and ageing of network assets have set and will further set new requirements for power systems. An often-quoted concept is the so-called "smart grid". There are different definitions for smart grid. The European Regulators Group for Electricity and Gas (ERGEG) defines smart grid as follows (ERGEG 2010): "Smart Grid is an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety". This definition describes in a way an "ideal" electricity grid or the ultimate goal to which development should be targeted. Rapidly developing information and communication technology sector and other technological development bring new possibilities for electrical energy systems. In the future there will be more communication possibilities, more measurements, more computation capacity, better modelling and more controllable resources available than previously. To improve the cost-efficiency of the system or to introduce improvements or new useful services worth money, the new assets and systems mentioned above can be used. New technologies can be used to develop the system to a "smarter" direction. In this paper, we postulate that the "smartness" of the grid is not in the use of new technologies, but in the advantages obtained by using the new technologies. In other words, the smartness is in the achieved cost-effectiveness of the system and/or in the improved operation and/or the new functionalities worth the additional money spent.

A general property of a smart grid is flexibility; the grid adapts to every situation in the best possible way taking into account the available resources. In a power system, production and consumption of electricity must be kept in a balance all the time (Bollen 2011, Kothari and Nagrath2004). In a traditional paradigm, electricity demand varies according to consumers' needs and the production units regulate their production in order to keep the balance (Bollen 2011). Thus, the production operates as the responsive resource. Another possibility is that also some of the consumption would response to keep the balance between production and consumption (Bollen 2011). The way consumers can participate to maintain the power balance is to temporarily lower or increase electricity consumption at certain times based on for example dynamic electricity pricing. To some extent, consumers (typically large industrial consumers) participate to the power balance management already today, but there is a growing debate and interest in also increasing the amount of consumers, especially household level consumers, involved. In addition to management of power balance, controllable consumption could also be used for a tool of electricity trade and operation of distribution grids. In order to utilize flexible electricity consumption, the consumer has to make some kind of a contract with some party of the electricity sector to achieve some benefit of the actions. In this paper, all of the consumption flexibility and responsiveness described above is called *demand response (DR)*.

Demand response is considered as an important part of future's smart grids. DR is quite a broad concept, and generally different types of "demand flexibility", excluding energy saving and other actions which change the amount of electricity consumption, is typically considered to be "demand response". A commonly referred definition for DR is presented in (DOE 2006): "Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized." More generally demand response means that electricity consumers change their electricity consumption in accordance with some input coming from some actor so that the actor and the consumers benefit from the action (Rautiainen 2015). In other words, demand for electricity responds to some input in a way that benefits all parties involved.

DR can potentially bring many benefits to different actors of the electrical energy system, and all DR applications have one common denominator: resource efficiency (Rautiainen 2015). One of the main needs for DR is the increasing amount of intermittent renewable power generation, especially solar and wind power. DR offers new tools to integrate these new resources into the existing power grid. More generally, demand response can increase the utilization rate of assets and resources and thus boost their rate of return. DR also lowers the price of electricity and decreases the price volatility. DR can also improve the planning and usage of the electricity distribution networks and increase their reliability. Reliability could be enhanced e.g. by using DR to support the use of back-up connections during network faults (Rautiainen 2015). However, there are many actors in the electricity market, whose interests are partly in conflict with each other. This means that the implementation has to be made carefully and with cooperation between market actors. In this article, demand response is discussed from various viewpoints in order to give the reader a holistic view on the subject. North-European electricity market, especially Finnish environment, is used as an example, as it represents a good example of modern, well-working and sophisticated electricity markets. Finland is part of very liquid wholesale market where majority of the electricity is traded in hourly basis in the power exchange, and when this is combined with extensive smart metering (>99% of Finnish customers have smart meters at their premises), it enables extensive use of DR.

Actors and market places of demand response

There are several actors around the concept of demand response. One of the most important actor is the electricity consumer ("customer"). As described in the definition of demand response, an actor offers inputs for the customer to change his/her electricity consumption. The aim is that both the customer and the incentivizing actor benefit from the changes in the consumption pattern. Possible actors are for example the following (Rautiainen 2015):

- Electricity retailers

- Transmission system operators
- Distribution system operators
- Aggregator.

In the following, we discuss of the roles of each of the actor.

Electricity retailer

Electricity retailer (ER) is a very important actor in demand response scheme. In present market structure of Nordic countries, all types of demand response have direct financial implications to the retailer. The core operation of an ER is to sell electricity to its customers and make profit. In North-European electricity market, the typical way of doing business is to buy electricity from the wholesale market and sell energy to the customers with some kind of an electricity contract. At the present, electricity is traded in hourly basis in the North-European power exchange (Nord Pool Spot) or bilaterally, although there is a common European roadmap for moving to 15 min market unit. In order to buy or sell electricity in the power exchange, the retailer (or a producer) has to make binding bids for the markets, and a bid includes volume and price combinations for a certain hour/hours. There are two market places in the Nordic power exchange: day-ahead and intra-day. In addition to electricity trade, different financial derivative products are used by producers and ERs to hedge the volume and the price of the electricity production or procurement.

For the electricity consumers, there are different types of contracts for electricity. Presently, most of the customers in the North-European market buy electricity with a fixed price contract. There are also contracts, offered by various retailers for customers with hourly pricing. This means that the household level customers have different electricity price for every hour based directly on the prices of the day-ahead market of the power exchange. This kind of a contract makes it possible for the customer already today to do demand response by shifting consumption to the cheapest hours. In order to verify the shift, the consumption of the customer has to be measured in hourly basis. For example in Finland, there is roughly 100% coverage of so-called AMI (Automatic Metering Infrastructure) meters being able to measure the consumption in hourly basis. If the customer would have good opportunities to shift the consumption in time and the price volatility would be sufficient, customers would be able save money.

If the customer would do demand response described above, this would have many implications to the ER. A retailer has to estimate the consumption of its customers for every hour in order to purchase the right amount of energy from the power exchange. If the consumption estimate is too low compared to the realized consumption, the retailer must buy the difference from the so-called balancing energy market, and if the consumption estimate is too high, the retailer has to sell the surplus energy to the balancing energy market. In both of the cases, the retailer may suffer a monetary loss compared to the situation where the consumption estimate would match the real consumption. These monetary losses can eventually be quite high. If the retailer had price sensitive customers if the retailer could forecast how consumers react to different prices, the retailer could take this into account in its bids. This means that with low prices, the volumes would be larger and with high prices, the volumes would be lower. This would help the retailer to manage its own balance and if this kind of electricity demand price responsiveness would be applied broadly, it could lower the general price level in power exchange. If the retailer had price sensitive customers and could not forecast the behavior of the customers, the price sensitiveness might still help in the procurement, but this depends on the situation. Depending on the signs of the imbalances in different hours and the balance power prices compared to power exchange prices in corresponding hours, the load control of the customers might cause financial benefit or harm to the retailer. Nevertheless, an imbalance always includes a risk of financial losses, and minimization of the imbalance is part of the retailer’s risk management. As every retailer has this balance responsibility, this has implications to all types of DR and therefore is a very important thing to understand.

If a retailer can estimate a probable forthcoming imbalance, the retailer could try to compensate it. One option is to trade in the intraday market. Another possibility is to apply some DR measures to minimize the deviation. The retailer could estimate the real consumption of its customers close to the trade hour and then try to decrease the deviation by customer load control. Estimations can be carried out before or during the trading hour under investigation.

There are some uncertainties on whether DR markets could effectively be used in the future. One critical part is that DR should be attractive enough in order to be applied, as for big consumers the risk of changing the consumption pattern might pose a risk to the core process, e.g. production line/process, of their business. A small profit from DR cannot be exploited if it endangers or even complicates the core process too much. There are also some challenges related to DR of small customers. As mentioned earlier, a great majority of the small customers today are buying their electricity with a fixed price. Fixed price contracts are very secure from customer point-of-view, and they can be price competitive compared to power exchange price based contracts. Security/predictability is a significant factor for the customers (Ruokamo and Kopsakangas-Savolainen 2016).

The potential benefits of DR in the electricity trade in the long run depend on many things such as consumption and customer behavior estimation capability of the retailer and the way and level of hedging of the procurement. However, none of the factors mentioned above are of any importance, unless the end customers have an incentive to alter their behavior during high or low prices. Therefore spot based retail pricing plays a vital role in retailer driven DR. Later in this article, potential of retailer driven DR is investigated as a case study.

Transmission system operator

Transmission system is the backbone of the power system and comprises typically a nation or large area wide meshed network to which all the big power plants and smaller distribution networks are connected. Two essential tasks of a transmission system operator (TSO) in the Nordic countries are to ensure the reliability of the power system and to advance the operation of the electricity market. Implementing DR to the electricity system potentially serves the needs of both of these major tasks. From TSO’s interests, DR should be applied in different types of reserve markets or the wholesale electricity market (by energy producers/retailers).

In reserve markets, the TSO purchases capacity for power system reserves from the reserve owners. Power system reserves are used to ensure the reliability of the whole power system by making sure that the balance between power production and consumption is maintained. The reserve capacity can be power plants or controllable loads. This means that there is already today market for DR for the needs of the TSO. The Finnish TSO Fingrid uses mostly reserves owned by other parties in a market-based manner, but it has also some reserves of its own. Reserves can be divided into two main types: automatically and manually activated. Automatically activated reserves are typically frequency controlled. In a conventional AC power system, change in frequency of the voltage works as an indicator of the balance between power production and consumption (Kothari and Nagrath 2004). The frequency decreases if the total power production in energy conversion processes of power plants is less than total energy consumption in the system. And vice versa: in the case of power surplus the frequency rises. Information on frequency is used to adjust the production of the automatically activated reserves in order to maintain the balance between power production and consumption.

The manually activated reserves have typically longer activation times than with automatically activated reserves. Automatically activated reserves require typically response times of some seconds to some minutes. In Finland, this range is 5 s…3 min. Manually activated reserves require typically activation time of 15 min. As a comparison, in the day-ahead market of the power exchange, hourly prices of the following day are announced at the previous day at around 13:00 CET. This means that there is about 11–35 hours before DR load control actions have to be realized. This is much longer time as with TSO reserves. Considering the fastest types of reserves, it might be challenging to construct a system which could control a large number of small household level loads spread out over a large geographical area fast enough. Frequency controlled reserves offer a possibility to make the control decisions locally near the physical load based on the local frequency measurement. This kind of control could be extremely fast and offers interesting possibilities for the future. However, if the required reaction times are some minutes, it is possible to spread the required information rapidly enough to a large number of individual places using modern communication technologies.

Distribution system operator

Distribution system operators (DSOs) are responsible for planning, building, maintaining and operating the local distribution networks which are further connected to the national transmission grid. In general, the holistic societal target is to minimize the electricity infrastructure costs within certain boundary conditions such as the level of service of DSOs. DR could be applied also in the operation of distribution networks and thus be taken into account in distribution network planning.

In general, the aim of the network planning tasks can be presented as the following minimization task:

$$\min \sum_{t=1}^{T} (C_{inv}(t) + C_{loss}(t) + C_{out}(t) + C_{maint}(t)), \quad (1)$$

where C_{inv}, C_{loss}, C_{out} and C_{maint} represent the present values of investment, loss, outage and maintenance costs, respectively, of the years $(1, 2, \ldots, T)$ of the planning horizon (Rautiainen 2015). Of course, different technical and electrical safety related boundary conditions have to be fulfilled. In principle, applying DSO driven DR could decrease at least the three first cost components of (1) (Rautiainen 2015). Lowering the investment costs implies e.g. to an increase in the utilization rates of network and/or reducing the need for back-up connections. This is one form of resource efficiency. If DR would be used to flatten load profiles of different network components, this would mean lower losses and lower related costs. In addition, it is possible to improve the reliability of the distribution grid using DR by for example in unusual network configurations during disturbances to cut the peak power in order to enable the use of a back-up connection, which would normally have insufficient transfer capacity.

Today in Nordic countries, DSO's set incentives for the small customers to do demand response in a form of dynamic distribution tariffs (Lummi et al. 2018). Traditional option is the two-time tariff, which means that the distribution fee (in cent/kWh) is lower during night-time. This incentivizes the customers to shift consumption to the time of lower tariff rate. Another, novel option for DSO driven DR are the power based distribution tariffs (PBDT), which are already being implemented by some DSOs at least in Finland and Sweden. There are different options for PBDTs, but the idea is that the distribution tariff sets a price (e.g. in €/kW) for the peak power of the customer, measured typically as an average power over one hour. This kind of distribution pricing incentivizes the customers to manage their peak consumptions. In the future, DSOs might also set also other types of DR services, such as managing disturbances in the distribution network using direct load control (Rautiainen 2015).

Aggregator

Currently in Finland there are two "DR market places" where small electricity consumers can directly participate and to which many small consumers participate already today:

a. Electricity retailers' "time-of-use" contracts

b. DSOs’ time-of-use and power based distribution tariffs.

The turnover of the retailer comes typically from the consumption of a large number of individual customers. Their total consumption is aggregated in so-called balance settlement process in order to know how much energy each of the customers consumed every hour. In both of these “DR market places” individual consumer can participate in the market because the necessary infrastructure to verify the DR actions has been installed, i.e. electricity consumption meters, and also “DR suitable” electricity contracts and distribution tariff products are available.

Considering for example reserve markets of the TSO, it is not possible today for a small consumer to directly participate for these DR markets. Finnish TSO Fingrid sets two main requirements for the reserves, which are actually very generic and fundamental and thus relevant for all kinds of DR: controllability and verifiability. Controllability means that the load must be controllable in a proper way, and verifiability means that it must be possible to verify whether the load is really controlled in an appropriate manner. In order to fulfill these requirements, some infrastructure is needed. The requirements for reaction times of reserve markets are much shorter compared to the reaction time of power exchange price based DR. If there were infrastructure to control and verify the DR actions, there would also be appropriate contracts and products for the service.

Different DR market places have also different requirement for minimum capacity (in MW) of resources. For example in the market places of Finnish TSO, the minimum requirements vary between 0.1 MW and 10 MW. If small customers were enabled to participate in these markets, the minimum requirements would have to be changed or the requirements would have to be applied for an aggregated group of loads. It is clear that to have some impact on the power system, the load has to be large enough. To get commercial reserves, the Finnish TSO itself makes contracts with the large DR resource owners and also supervises the control tests. Doing this for thousands of small customers would be very hard in practice, and the cost for the control and verification system and supervision of the control test would be very high per single small customer.

For these reasons, it would be beneficial to have a DR infrastructure, adequate control test of the customer site and related contracts made in cooperation with some other party such as home automation manufacturers or DSOs installing next generation AMI meters to the customers. In this way the business model for collecting large number of small resources could be reasonable. The entity collecting and managing resources for DR is called a*ggregator* (another possible names are *service provider, DR operator or virtual power plant*). There are different thoughts about the role and tasks of the aggregator. In today’s Nordic market model, the aggregator is the electricity retailer who sells the energy for the consumers participating to the DR. This is a natural solution as the retailer has the balance responsibility in the market (cf. section 2.1) and it is on retailers’ interest to manage the consumption of its customers. However, the aggregator can be seen also only as a “technical service provider”, providing the infrastructure for controllability and verifiability purposes and offer the services to a retailer. The retailer could use the services of the aggregated energy resource in the electricity trade and it can also offer the services to other DR market places like reserve markets of TSO and possibly “ancillary service markets” of DSOs.

Demand response resources and infrastructure

To be able to operate, demand response requires controllable electrical loads, functional business models and appropriate infrastructure bundling the two first mentioned things to a working system. Whether the business models are the ones that exist already today or new ones, it is important that they enable reasonable business opportunities for companies and include customer-engaging elements.

The DR resources are owned by electricity consumers, which can be divided for example into three types: small, medium and large. Today in North-European power system the large electricity consumers such as big industrial facilities already participate to DR to some extent. However, the participation of medium-size (e.g. super markets) and especially small consumers is mostly restricted to the use of two-time tariff based DR. Especially for medium-size consumers, the implementation costs of DR might be moderate in many cases compared to the expected financial benefits.

Not all the loads are usable for DR purposes unless there is an electricity storage device which would carry out the shifting the energy consumption of the loads to another points of time (Koskela et al. 2016). Resistive electric heating, air conditioning devices and electric storage water heaters are the most interesting DR resources of today's small electricity consumers. Also different heat pumps might have some potential. All these appliances are interesting DR resources because they typically consume significant amounts of electricity, their nominal powers can be high and it is often not very critical when the load consumes the electricity, i.e. the consumption of the load can be shifted in time. In addition to shiftable loads, there are some loads which can be curtailed for a while like lighting. In addition to the conventional loads, electric vehicles are a new type of DR resource which might become a non-negligible one in the future. Electricity consumption and also the controllability of electric loads depend on many things. Especially the consumption of heating and cooling loads depends strongly on the outdoor temperature. During warm weather there is only very little heating load available and during cold weather, the amount of cooling load is low.

In addition to the load or resource itself, the infrastructure needed to control and verify the operation of the resources is a very important part of DR. In practice there are many options for the DR control and communication infrastructure for small electricity consumers. At the moment in Finland, AMI meters or "smart" electricity consumption meters have been installed to almost all customers. The meters today have some capability to control the loads of the small customers. There are one or two relays in the meter (Honkapuro et al. 2014) which can be used to control for example electric heating loads in one way or another. There is at least one relay to realize the day-night tariff or seasonal tariff related load control. For small consumers it is estimated that there is roughly about 1800 MW (roughly 12% of the peak load in Finland) of loads currently connected to control relays of AMI meters in households (Honkapuro et al. 2014) in Finland. It is however under debate what kind of load control operations would be possible with the current meter fleet (Honkapuro et al. 2014, Koponen et al. 2014). The information systems of the DSOs form some bottlenecks for this DR capacity.

One branch of discussion has focused on whether or not a smart meter would operate efficiently as the "brain" which would control the loads and carry out appropriate communication with relevant DR actors. In practice, every electricity consumer in Finland has an AMI meter and thus using these in DR would lead to a very wide DR infrastructure. Also, as new generation of AMI meters will be installed in the coming years it could be very cost efficient to implement sophisticated DR functionalities in the new generation of meters. However, this scenario includes some risks at least in the present regulative and operational environment of the DSOs. The meters are owned by DSOs whose core task is to operate the distribution network. Offering a flexible and open platform for DR purposes for different parties and designing and installing the local load control systems at people's homes is not presently on the DSOs responsibility and the motivation and competence of DSOs to operate as a aggregator is questionable.

Another significant branch of discussion is the ability of different types of home automation (HA) systems, building automation (BA) systems or home energy management systems (HEMS) to manage the DR actions in the customer-end. HA/BA/HEMSs would be produced by companies in an open and competitive market. However, without standardized procedures and standardized and open interfaces the HA systems of different HA producers are easily very diverse and realization of large scale DR might become too complex. For example in Finland, some electricity retailers today power exchange price based electricity contracts with a load control device which can shift some of the load to cheap hours.

A very relevant question is how DR could be economically attractive enough for the customer, taking into account the customer site investments stemming from the DR related equipment and systems. A possible solution for this would be to use “benefit stacking” approach on the use of the DR resources. This means that the benefits of DR should be “fished” from many DR market places simultaneously. An example of this is that the same controllable loads would be used in accordance of retailer’s time-of-use contract and by participating to a TSO’s reserve market. Also, if the customer site DR control was conducted using HA/BA based systems, the investment cost for DR would not have to be very large. A HA/BA system could offer many functionalities such as

- Increased comfort and energy efficiency (control of room temperatures, lighting and air conditioning)
- Increased safety and security (integrated fire detectors, security alarms, water leakage alarm and prevention)
- System monitoring and supervision (monitoring of energy consumption, local energy production and water consumption)
- Back-up power systems (back-up power for full load, partial load or “light” load)
- Demand response services.

As the HA/BA system would anyway be purchased for many different purposes and needs, the DR functionalities required to the system would not necessarily bring about large additional costs.

New home automation systems diffuse slowly to the society as houses have typically very long lifetimes, and both building new houses and renovating old ones are made under many traditional paradigms, which change slowly. Therefore, it is likely that in order to get novel DR infrastructure in the customer end in a few years, the next generation of smart meters is the only hope.

A case study: demand response in the North-European electricity market

Different Nordic countries have different energy policies, which have impact on the potential of DR. Nordic governments all see DR having a role in the future electric energy system, both in national and regional levels. The national energy policies naturally have variation due to particular features of each state’s energy systems, and therefore DR has a different potential in each of the Nordic countries. Still, each of the Nordic states see e.g. technological development, the increase of intermittent renewable energy production and the need to control peak loads creating both opportunities and need for the use of DR (Rautiainen et al. 2017).

In this section, the DR attractiveness of the day-ahead market (Elspot) of the power exchange, is investigated in form of historical market data analysis and by projecting the factors, which redirect the development of the markets in the future. The result of this section are based mostly on (Rautiainen et al. 2017).

In the Nordic day-ahead Elspot market, the potential economic benefits for a DR operator does not come from the average price level in the market, but from the short-term (e.g. within a day) variation of the prices. The DR operator would shift the consumption from the expensive hours to cheap hours and in this way harvests the benefit. Therefore, for the Elspot market, the price volatility within a day is being investigated.

The Elspot market includes different bidding areas. Fig. 1 presents the bidding areas in the North-European market including Nordic and Baltic countries. Sweden, Norway and Denmark have 4, 5 and 2 bidding areas, respectively. Finland, Estonia, Latvia and Lithuania all have only one bidding area. The idea of the bidding areas is that producers and energy sellers/retailers make bids in their bidding areas out of which the system price for the whole market is calculated, and if the transmission capacity forms physical bottlenecks preventing the trading to be realized as such, different price areas are being formed based on the bottle necks. The price data of the four years, from 2013 to 2016, are mainly being used in the study with the exception that for Latvia the year 2013 is excluded as the Latvian bidding area of the Nordic electricity exchange Nord Pool Spot was opened in the mid 2013.

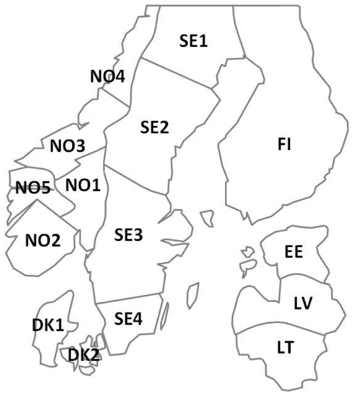

Figure 1. Bidding areas in Nordic/Baltic Countries in Nord Pool day-ahead market Elspot.

Fig. 2 shows the four price related quantities in the bidding areas of Fig. 1. The figure shows the annual averages of four Elspot price (C) based quantities calculated on daily basis over the years of examination. The first quantity is the annual average daily price range:

$$\mu_{\Delta C} = \frac{1}{N}\left(\sum_{day=1}^{N}(\max(C_{day}) - \min(C_{day})\right) \tag{2}$$

where C_{day} is the vector of hourly prices of the day: $C_{day} = \{C_{1,day}, C_{2,day}, \dots, C_{24,day}\}$. The second quantity is the average daily standard deviations $\sigma_{\Delta C}$ of the prices over the year. The third quantity is the average annual Elspot price.

Fig. 2 shows that in 2016, among the Nordic countries Finland had the highest volatility, but the Baltic countries had the highest volatilities among all the bidding areas. Volatilities are also quite high also in Denmark, but in Sweden and especially in Norway the volatilities are low. Low volatility implies poor attractiveness of Elspot based DR. For countries which have very hydropower-intensive electricity production, like Sweden and especially Norway, the low volatility is a natural thing. Also, in Finland there is relatively high amount of temperature dependent load, which increase the volatility.

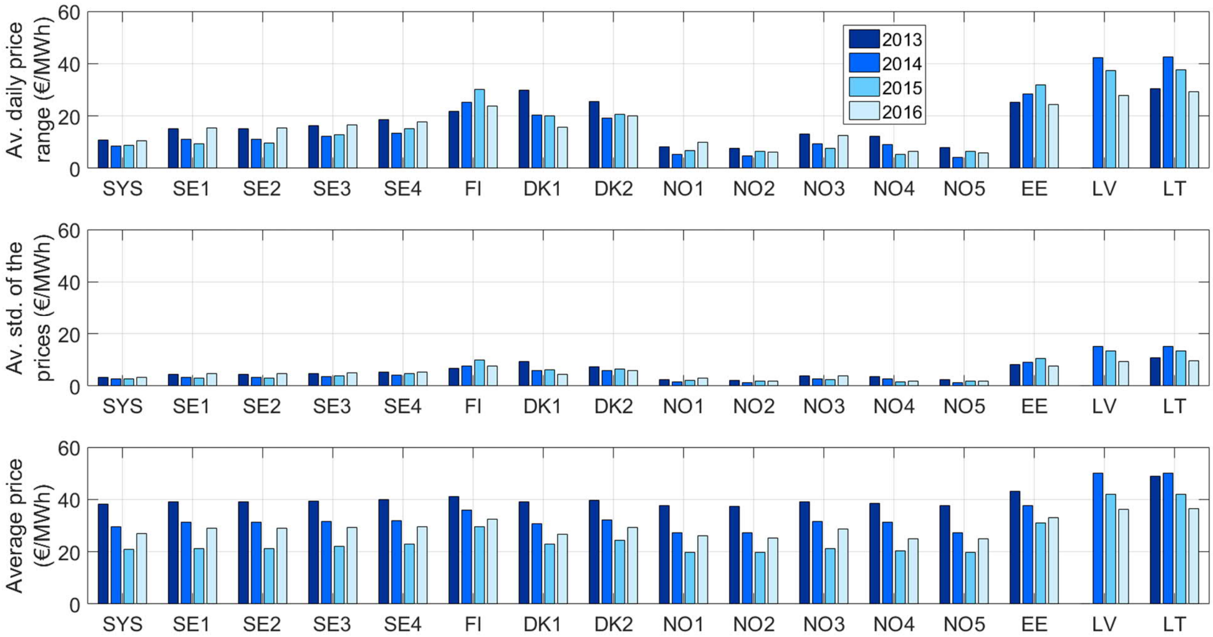

Figure 2. Average daily price ranges, standard deviations and prices of the Elspot system price and the area prices in 2013–2016.

When looking at the Fig. 2, it can be observed that there is no clear trend in the volatility, which would apply to all the investigated countries. In Finland, there was a clearly rising trend between 2013 and 2015 in volatility, but in 2016 the volatility decreased. There are many potential reasons for this kind of development. Firstly, the amount of installed wind power capacity has increased from 448 MW at the end of 2013 to 1553 MW at the end of 2016. Increasing wind power capacity potentially increases the volatility, which is illustrated in Fig. 3 showing a real situation in the market in January 2017. The figure shows correlation between prognosis of wind power production and the Elspot price in Finland. The prognosis data of Fig. 3 is from the Finnish TSO Fingrid's open data service, and is updated at 12:00 for the next day, and is therefore a prognosis of the next 36 hours. Prognoses are used when a wind power producer plans the bids for the Elspot market. It can be seen from Fig. 3 that there are some periods of time where the wind power prognosis is very low and the Elspot price relatively high. For example, 16.1.2017 at 17:00–18:00 there is a price peak of 117.1 €/MW, and the wind power prognosis is only 94.65 MW for the same hour.

Another factor increasing volatility in Finland is related to the fact that the average Elspot prices (see Fig. 2) have been decreasing over the last years (although in 2016, the average price increased but remained still below the prices of 2013 and 2014). This has meant that especially the profitability of condense power plants but also combined heat and power (CHP) plants have decreased, and significant capacity of these power plants have been ran down and will probably be ran down more in the future. As dispatchable capacity decreases in the system, this increases the price volatility.

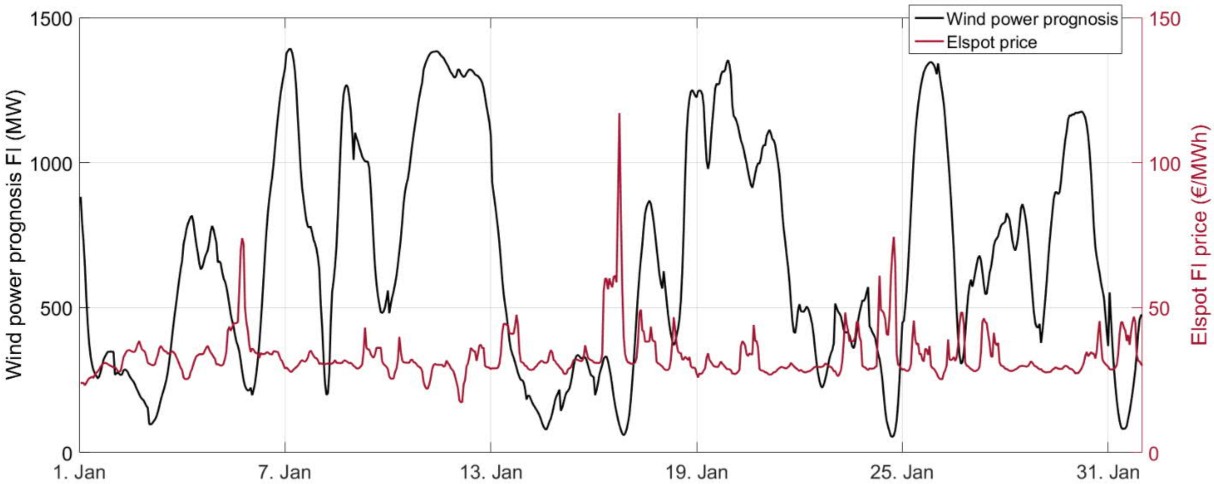

Figure 3. Windpower progosis and Elspot FI price during January 2017.

One significant factor decreasing the Elspot price volatility in Finland in 2016 was the commissioning of the 700 MW HVDC transmission line “NordBalt” between Sweden (SE4) and Lithuania. NordBalt connection makes enables power transfer from Sweden to Finland through Baltic countries. Figure 4 shows the daily price range in Elspot FI price in 2015 and 2016 together with the hourly power exchange of NordBalt in 2016. The figure illustrates the fact that constructing new transmission lines potentially decreases the price volatility.

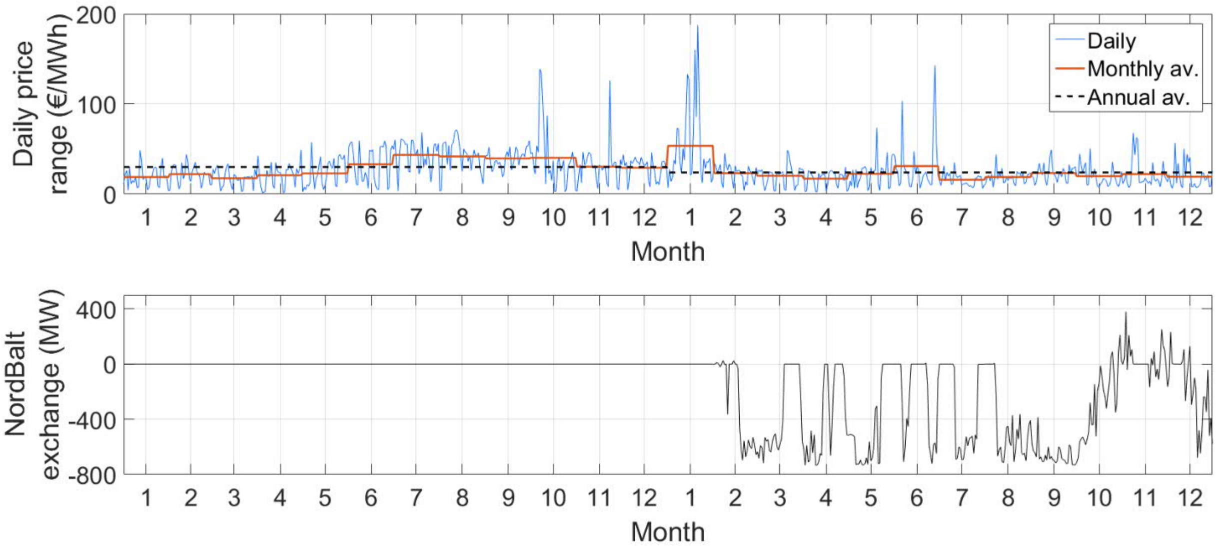

Figure 4. Price range of Elspot FI and the hourly exchange (negative power means export to LT) of NordBalt connection over years 2015 and 2016.

As a summary, the attractiveness of DR from the Elspot market viewpoint is dependent on many things and the future includes many uncertainties. Some of the factors affecting the volatility are the following:

- Increasing amount of intermittent (renewable) power. There is an existing trend and a strong vision of significant increase of wind and solar power capacity in the North-European transmission system. This kind of capacity potentially increases the volatility, as the production is purely weather-driven, and does not depend on the power demand or other market related things.

- Amount of total capacity of nuclear power plants, which do not participate to regulation of the power balance in the system. These kinds of new nuclear units and the continuation of the existing units generally decreases the price level, but increase the volatility in proportional or even absolute manner.
- Decreasing amount of condense power and combined heat and power (CHP) plants. Nuclear power, renewable power and other low variable cost electricity production capacity tend to decrease the average price level of the market, which further decreases the profitability of present condense power plants and CHP capacity. The decrease of flexible and dispatchable power plants increases the volatility.
- New internal transmission lines within the Nordic system and stronger connection to continental European system. Transmission lines bind the system to more coherent system, which typically, but not necessarily always, decreases the volatility. There are some plans to build new transmission lines in the Northern Europe.

As a whole, it can thought that the price volatility and thus the attractiveness of DR in the Elspot market is increasing in the future. In addition, the market places in North-European electricity market are under continuous development, and offer, together with technological and business model related development, potential platform for resource efficient and sustainable power system in the future.

Conclusions

Demand Response is a broad concept including all kinds of flexibility in the electrical energy demand. Moving towards more sustainable energy system offers very promising opportunities for demand response, but the opportunity can also be seen another way around: demand response offers interesting tools in achieving resource efficient and sustainable power system in the future. This however requires attractive enough market places and relevant business models including building and operating proper DR infrastructure.

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