Impact of Demand Response on the Risk Profile of Electricity Retailers in North-European Electricity Market

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***Abstract*— Large scale Demand Response (DR) has different impacts on different market actors. The impacts depend significantly on the market actor and the operational environment. The impacts of DR on electricity retailers (ER) in the North-European electricity market are discussed in this paper. DR is a double-edged sword for an ER. On one hand, DR offers a potential tool to improve the operation in the electricity market, but on the other hand, DR poses also risks to the ER. The impacts of DR on ERs depend on many things like the nature of the controllable demand, the characteristics and the rules of the market place in which DR is being operated and the structure and the nature of the electricity contracts made with the customers. These things are discussed in depth in this paper. A case study is presented related to DR based on day-ahead area prices in Finland. The case study shows that on average, the imbalance costs induced by DR to the retailer can even be positive (positive cash flow), but the risk of significant additional costs remain and might even be increasing.**

***Index Terms*-- Demand response, electricity market, risk management**

I. Introduction

Electrical energy related demand response (DR) has long traditions both in practice and in research. During the past few years, DR has appeared in the spotlight in a new way. This is due to general technological advancement especially on the information and the communication technologies, development of electricity infrastructure (especially rollout of smart meters), and rapidly increasing amount of renewable intermittent energy sources like wind and solar power. In addition, the rapidly decreasing prices of lithium-ion batteries [1] have increased the interest in DR, as energy storages might offer a significant tool for the purposes of DR in the future.

Large scale DR has different kinds of impacts on different market actors. The impacts depend significantly on the market actor and the operational environment. In this paper, we discuss on the impacts of DR on electricity retailers (ER) in the North-European electricity market. DR is a double-edged sword for an ER. On one hand, DR offers a potential tool to improve the operation in the electricity market e.g. in form of balance management and additional revenue source, but on the other hand, DR poses also risks to the ER e.g. in form of imbalance costs. The impacts of DR on ERs depend on many things like characteristics of the flexible loads, the market rules, the properties of the "market place" in which DR is being operated and the structure of the electricity contracts made with the customers. These things are discussed in in this paper. In addition, a case study is made using real market data.

This paper is organized as follows. In Section II, North-European electricity market environment is briefly introduced, different market places where DR can be applied is are explained and the impacts of DR on the risk profile of an ER in different market places are discussed. In Section III, a case study regarding imbalance risk of the day-ahead market price based DR using real market data is made. In Section IV, conclusions are made and future work is proposed.

II. DR in the North-European electricity market

A. North-European electricity market

Nordic countries have long history in common electricity market. In recent years, common European electricity markets have been under construction [2] and new interconnections have been built between the Nordic countries and the continental Europe. This paper defines "North-European" (N-E) to cover Finland, Sweden, Norway, Denmark, Estonia, Latvia, and Lithuania. From these regions, there are interconnections to other countries, but the focus of this paper is in N-E electricity market environment.

In N-E countries, DR can be operated in multiple market places. The actual market places and their rules can vary between different countries, but the special focus in this paper is in the Finnish market environment. Possible DR market places today are the following.

1. Day-ahead market (D-A)

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2. Intraday market (ID)
3. Balancing energy market (BEM)
4. Balancing capacity market (BCM)
5. Automatic frequency restoration reserves (aFRR)
6. Frequency containment reserve for normal operation (FCR-N)
7. Frequency containment reserve for disturbances (FCR-D)

These market places have different rules, price formation mechanisms and other properties. The D-A market is the most liquid market place, and most of the physical electricity in the N-E electricity market is traded in the D-A market. ID market offers an additional tool for trading near the operating hour e.g. for balance management. BEM (called also manual frequency restoration reserve (mFRR) energy market) is a very important market place, which is used for two purposes: to manually restore the grid frequency near to the nominal value and to define the imbalance costs related to electricity trade. BCM (called also mFRR capacity market), run by the TSO is used to ensure the TSO has enough manual reserve to cover the dimensioning fault in all situations. The idea of BCM is to work together with BEM: "A reserve provider whose capacity bid is accepted on the balancing capacity market is obliged to give upper balancing energy bids to the balancing energy market in exchange for a financial compensation." [3] aFRR is used to restore the grid frequency back to the nominal value, and currently the reserve is used only during certain hours of day. FCR-N and FCR-D are used to contain the frequency in defined limits in normal operation states and during disturbances, respectively. A today's possible market place, which was not mentioned in the previous list, is the "peak load capacity" or "strategic reserve", which is used to secure the supply security in situations of the Finnish power system where the planned electricity procurement is not sufficient to cover the anticipated electricity consumption. [3] The procurement of this reserve is based on long contracts. One can have more information on the market places e.g. in [3] and [4].

In addition to these, N-E transmission system operators (TSOs) plan to launch a new reserve type "Fast frequency reserve (FFR)" in 2020, which would represent a very fast reserve for limiting the frequency drop after a major fault in situations with low power system inertia [5]. In addition to these market places, new market place entrants for the flexible resources might be available in the future for example in the distribution grid domain [4]. In principle, controllable demand could be used in all of the market places, but in practice, some of the market places fit better for controllable demand than others. It is also possible to use the same flexible load/resource in many of the previous market places (benefit stacking) to maximize the value of the flexible resource.

B. Imbalance management

In present market structure of N-E countries, all types of DR have direct financial implications to ER. At the present, electricity is traded in hourly basis in the power exchange (Nord Pool Spot) or bilaterally, although there is a common European roadmap for moving to 15 min market time unit in some market places and functionalities. In order to buy electricity in the power exchange, an ER has to make binding bids for the D-A and/or ID markets, and a bid includes volume and price combinations for a certain hour/hours. In order to buy right amount of energy for every hour, the ER has to estimate the consumption of its customers. If the consumption estimate and hence the amount of purchased energy is too low compared to the realized consumption, the retailer must buy the difference as so-called consumption imbalance power (CIP) from the TSO in the imbalance settlement process. In turn, if the consumption estimate is too high, the retailer has to sell the surplus energy with the price of CIP. In both of the cases, power surplus or power deficit, 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. The price of CIP is defined for every hour by using certain rules based on the activated bids in the balancing energy market (BEM). In the case where balancing energy bids have been activated, the balancing energy price is used. If no balancing energy bid activations have been made, the D-A area price of Finland (Elspot FI) is used as the purchase and selling price of consumption imbalance power. [6] The previous description is the present situation. However, the N-E balance and imbalance management framework is going to be renovated in the coming years. However, the main principles considering this paper remain pretty much the same. In many cases, DR actions cannot be forecasted in such way that the ER could compensate the imbalance in the market. This further implies that DR poses a risk to the ER in form of imbalance related costs. From the perspective of ER, this is the most important risk component related DR.

DR offers also a potential tool for ER to manage certain risks. If an ER can forecast a probable forthcoming imbalance, the ER could try to compensate it. One option is to trade in the ID market. Another possibility is to apply some DR measures to minimize the deviation. ER could estimate the real consumption of its customers close to the operating hour and then try to decrease the forth-coming deviation with DR. Estimations can be carried out before or during the operating hour. Another example of DR as tool for risk management is the active participation of the ER's customers in the D-A market price based DR in a way that the ER could either directly control the consumption of the customer or in other way forecast pre-hand how the dynamic pricing changes the electricity consumption of customers. This would offer ER a dynamic tool optimize its operation in the electricity market.

C. Impacts of DR for an ER

There are many factors affecting the effects of DR on the ER. The most fundamental affecting factors are the following.

- The characteristics of the contract between ER and the owner of the flexible load (customer of ER)
- Nature of the flexible load (or other resource)
- Rules and characteristics of the market place

1) The characteristics of the contract between ER and the owner of the flexible load

From the viewpoint of electricity consumer, the freedom to use electricity based purely on the needs of the consumer is a great value. Therefore, the ER (or perhaps an aggregator or other DR operator depending on the market structure and rules) has to offer some financial or other compensation for its customers in order to encourage customers to change their consumption patterns (probably using automation). Different market places for flexibility offer ER different levels of income possibilities, and the level of compensation for the customer affects of course the profitability of DR for the ER.

2) The nature of the flexible load

There are roughly two types of flexible loads, which are illustrated in Fig. 1. In the first type, it is possible to make a DR action including only a unidirectional change in the consumption: to cut or increase the load without need to compensate the change later. A good example of this is greenhouse lighting. In a case of need to decrease load (need for "up-regulation" DR), the greenhouse lights can be shut down for a while and later there is no need to compensate the lightless period with additional lighting. The lightless period slightly decreases the growth of the plants, but the greenhouse owner gets a monetary compensation for the DR action. The second type of flexible load is transferable load (load shift). In this type of load, load control actions increasing or decreasing the consumption induces later a counteractive change in the consumption. An example of common load like this is electric heating. If one switches off an electric space heater for a while, the off-switching causes later a "rebound" as the heater recovers the temperature back to near the setting value. In case of on-switching, the rebound is opposite. Battery and other energy storages used to realize consumption changes work also with the "load shift" principle.

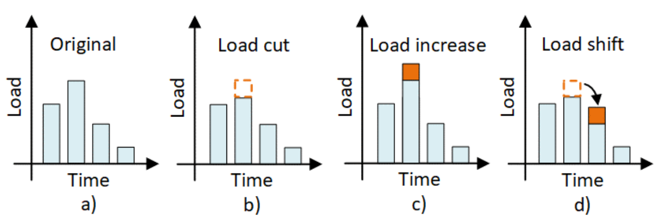

Fig. 1. The principles flexible load compared to the a) original load: b) load cut, c) load increase and d) load shift.

Flexible loads can be divided into two types also based on the control access of the ER: direct or indirect load control. In the direct load control, ER makes contract with the customer defining the rules how ER can directly control the load (remotely). In the indirect load control, the ER sets an indirect "control signal" such as varying price, and the customer decides independently from the ER on when and how to control the load.

The nature of the flexible load has an impact on the ER via the imbalance settlement mechanism of the N-E electricity market. As explained above, in many cases the DR actions of the customers are more or less unpredictable for the ER at least from the balance management viewpoint. In many cases, DR actions cause changes in the balance of the ER. In case of unidirectional loach change, the possible change in the balance of the ER happens only during the hour(s) under the load control activation hour(s). In case of load shift, also the rebound following the control action causes change in the balance of the ER. Let us consider an example: a domestic customer has an hourly priced electricity contract based on the D-A market prices, and the customer postpones water heating from an expensive hour h_1 to a cheaper hour h_2. It is assumed, that ER has purchased hourly energies from D-A market for its customers, which is the typical case on N-E countries. DR actions do not have effect on the D-A trades of the ER. If the ER cannot forecast the load shift in pre-hand, the impact of the DR to the ER is the following:

- The ER has to sell the surplus (postponed) energy of h_1 with a CIP price of h_1.
- The ER has to buy the additional energy of h_2 with the CIP price of h_2.

The customer gets the benefit corresponding to the price difference between h_1 and h_2, but the ER bears the risks related to the trades of CIP. The ER has bought the energy for the customers from the D-A market during the *previous day*, but the CIP prices are defined *during* the operating hour. This poses a significant risk for the ER as for example a fault in a big power plant or in major transmission lines, or a significant D-A price based DR might cause unexpected and dramatic changes in the CIP prices in a very short notice. If the flexible load would comprise DR actions of e.g. greenhouse lights or other unidirectional load change ("load cut" or "load increase" in Fig. 1), the effect related to h_2 would be removed. This means that for ER, "load cut" or "load increase" type flexibility induces smaller risk for ER than "load shift" type.

3) Rules and characteristics of the market place

The impact of DR action on the imbalance of the ER in the previous example was related to the D-A market price based DR. The rules for other market places are different. Table I presents characteristics of some DR market places. In the table, two aspects are presented: incentives for the customer and to the ER for participating to DR.

There are numerous ways for ER to construct the customer incentive system for DR. For contracts, which are based on the prices of D-A market, the base of the incentive for the customer is clear: the differences in the hourly prices and related cost savings. In other market places, such a clear incentive mechanism cannot be seen, but some kind of reward like fixed monthly premium should be offered to the customer by the ER.

The motivation or the incentive of DR for the ER depends on the market place. Considering only incentive of ER to offer D-A price based contracts (not including DR) to the customers is that with the contract the customers would carry part of the price risk. However, the incentive of ER to support D-A price based DR is not so straightforward. If the customers would have a D-A price based contract and the customers would do DR, they would have possibility to have a very competitive electricity contract, which would be a good thing to the ER offering the contract. However, as described above, D-A price based DR brings also some risks for the ER. The ID related demand response is different from D-A. ER can use ID market place together with DR to manage imbalance costs, as explained above, but this most likely requires direct load control contract with the customer. In other market places, the market place offers directly compensation for the ER based on the pricing mechanism of the market. Table I shows the quantification of the incentives for some of the market places. In BEM, the TSO pays the BEM price for the activations, and the imbalance caused by the activation is taken into account in the imbalance settlement taking the related cost away. This means that compared to the example presented in II.C.2, the effect of hour h_1 would be mitigated. However, the imbalance related cost for the possible rebound is always on the responsibility of the ER. The same situation applies also for BCM, aFRR and FCR-N. For FCR-D, the TSO pays only for the capacity, but the imbalance costs related to both activation and rebound are on the responsibility of the ER.

TABLE I. CUSTOMER INCENTIVES AND ER INCENTIVES FOR DR IN DIFFERENT MARKET PLACES [3].

Market place	Incentive for the customer	Incentive for the ER
D-A	Savings via the differences of D-A market prices	Competiveness of the contract for customers (includes the risk of imbalance costs).
ID	Compensation offered by the ER	ID trade with direct load control offers a tool for the ER.
BEM	Compensation offered by the ER	BEM price – possible rebound imbalance cost
BCM	Compensation offered by the ER	BCM price – possible rebound imbalance cost
aFRR	Compensation offered by the ER	aFRR capacity price fee – possible imbalance rebound cost
FCR-N	Compensation offered by the ER	FCR-N capacity price – possible rebound imbalance cost
FCR-D	Compensation offered by the ER	FCR-D capacity price – imbalance costs for both activation and rebound

III. CASE STUDY

A. The main idea and data

In this paper, a day-ahead (D-A) market price based DR case study in Finnish operational environment is presented. In Finland, >99% of consumers have smart meters [7]. These meters enable hourly pricing of electricity based on the D-A area prices of Finland (Elspot FI). This means that every hour has its own price for electricity. Also the imbalance settlement is made based on the hourly measurements and therefore it is possible for the consumers to do demand response by shifting consumption to the cheapest hours. At the end of 2017, about 9% of all consumers in Finland had hourly priced contract [7], and these consumers had therefore readiness for DR.

As explained in Sections II.B–C, DR brings imbalance risks for the ER. In the case study, Elspot FI price related imbalance risk of a retailer is investigated. The idea of the case study is the following: customers of ER do DR and shift their consumption from high price hours to low price hours. Load shift is the most reasonable type of controllable load for most of the consumers, especially households, and therefore the imbalance risks related to load shift type DR is investigate din the case study. It is also assumed that the ER cannot forecast the DR, and therefore DR causes imbalance to the consumption imbalance of the ER and the imbalances would be settled normally as CIP. In the case study we tried to quantify the imbalance related risk in the Elspot FI driven DR by using real market data. The data comprises the real hourly Elspot FI prices (Fig. 2) and the consumption imbalance power (CIP) prices (Fig. 3) in Finland in 2017 and 2018.

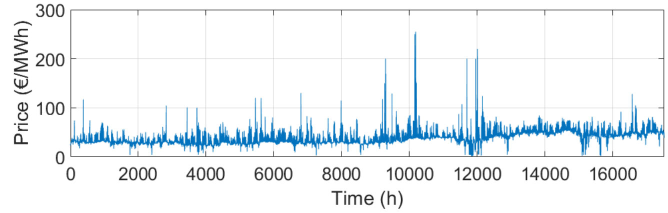

Fig. 2. Hourly Elspot FI prices 1.1.2017–31.12.2018. (Data: Nord Pool)

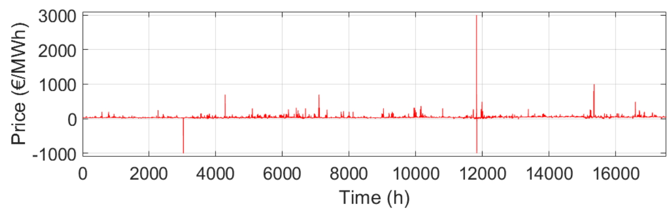

Fig. 3. Hourly consumption imbalance power (CIP) prices 1.1.2017–31.12.2018. (Data: Fingrid Open data [6])

In the case study, we calculated in a daily basis the difference of CIP prices of the *highest* Elspot price hours (from which the consumption would be removed) and the *lowest* Elspot price hours (to which the consumption would be removed). The difference would represent the imbalance *risk in €/MWh* of the DR action. In addition, TSOs charge CIP volume fee (in Finland 0.5 €/MWh), but these kinds of charges were excluded from the study. We calculated two different quantities for every day of the two year period:

a. The difference of the CIP prices between the hour of the *highest* Elspot FI price and the hour of the *lowest* Elspot price hour of the day.
b. Same as the previous but the difference is calculated from the *average CIP price* of the *3 hours* having the *3 highest* Elspot FI prices of the day and the *average CIP price* of the *3 hours* having the *3 lowest* Elspot hours of the day.

The first quantity tells only the imbalance risk in the case where consumption would be shifted between two individual hours. In the second quantity, it is assumed that consumption is shifted from three "expensive" hours to three "cheap" hours. We calculated both the quantities for two load shifting schemes:

i. The load can be shifted wihin all hours of the day (24 h)
ii. The load is shifted from the first night-time hours (when it normally is) to the cheapest Elspot hours of the night-time (22:00–07:00).

The idea behind this is that the distribution tariff (so called two-time tariffs set by distribution system operators) encourages many domestic consumers in Finland to do e.g. water heating and space heating during night-time, and therefore the Elspot FI based DR would also be made during the night. This a is relevant scenario also from the Elpost FI price viewpoint, as mostly (but not always) the Elspot FI prices are the lowest during nights.

B. Results

Figures 4 and 5 show the *daily CIP price differences* together with the two-year average for DR actions of lengths of one hour and three hours, respectively. The differences are calculated for the whole day. Figures 6 and 7 present the same as Figures 4 and 5, but with the exception that the daily differences are calculated assuming load shift from the first nigh-time hours to the cheapest of the night-time hours. The figures show that occasionally there are big price differences, but *on average*, the imbalance risk for the ER seems to be positive. In one hand, this is surprising considering the fact that the ER did not forecast the DR actions at all, and still the on average the risk is positive bringing potentially positive cash flow to the ER. On the other hand, the result is not surprising. The imbalance caused by e.g. consumption forecast errors is different in nature from the imbalance caused by DR. Consumption forecast errors are typically more or less random, but DR causes *systematic* deviations in the imbalance. When there is high Elspot FI price (scarcity of production capacity compared to the demand), the prices of the BEM (defining also the prices of CIP) tend to be high too, and vice versa for the low price hours. It is also logical that the CIP price differences within night-time are lower than the differences considering the whole day, as the price differences are limited only to a proportion of the hourly prices of the day.

Although on average the risk seems to be, at least by looking historical price patterns, positive for the ER, the nature of the concept of “risk” should be remembered. As explained in Section II.C.2, it is always possible that individual events might cause huge and unexpected changes in the CIP prices with a very short notice, which bring significant risk to the unpredicted DR actions of the customers.

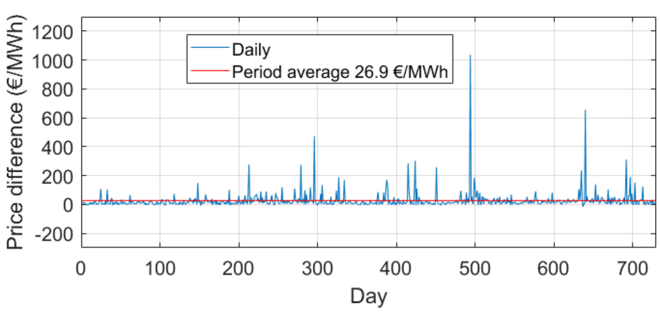

Fig. 4. The daily CIP price differences with the two-year average for DR of lengths of one hour. The daily differences are calculated covering the prices of the whole day.

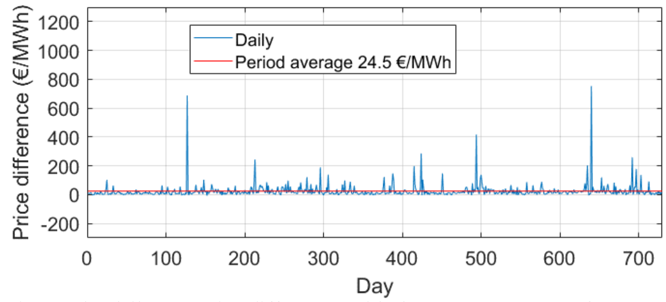

Fig. 5. The daily CIP price differences with the two-year average for DR of lengths of three hours. The daily differences are calculated covering the prices of the whole day.

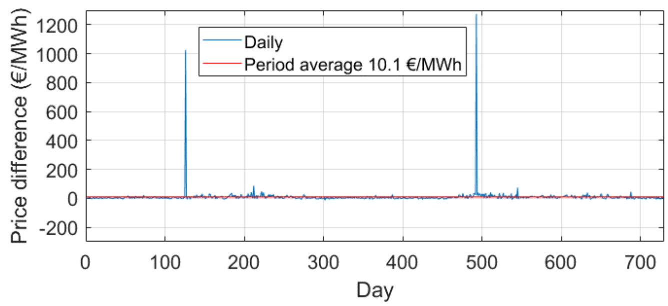

Fig. 6. The daily CIP price differences with the two-year average for DR of lengths of one hour. The daily differences are calculated based on the night-time load shift scenario.

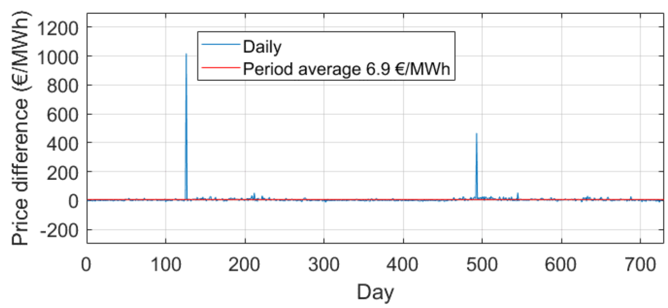

Fig. 7. The daily CIP price differences with the two-year average for DR of lengths of three hours. The daily differences are calculated based on the night-time load shift scenario.

IV. CONCLUSIONS

Demand response from the viewpoint of electricity retailer was discussed in this paper. Especially the imbalance risk induced by DR to the ER was under investigation. Characteristics of different types of controllable load and market places for DR were discussed from this point-of-view. A case study was also made, in which the imbalance risk of day-ahead market price based DR was quantified. The results of the case study show that on average, the risk of such DR might even be positive (cash flow for the ER) for the ER, but still risk of additional cost remain. Also in the future power system, which comprises different production mix and other characteristics, the nature of imbalance management might be different from today’s system. For example, large amounts of intermittent power production will increase the volatility of the CIP prices. Interesting future work in this field could contain e.g. case studies in other market places like BEM and FCR-markets.

REFERENCES

[1] Christophe Pillot, Current Status and Future Trends of the Global Li-ion Battery Market, Avicenne energy, 2018.

[2] European commission, Electricity Regulation (EC) 714/2009.

[3] Fingrid, Electricity Market, https://www.fingrid.fi/en/electricity-market/

[4] O. Vilppo, A. Rautiainen, J. Rekola, J. Markkula, K. Vuorilehto, P. Järventausta, Profitable Multi-Use of Battery Energy Storage in Outage Mitigation and as Frequency Reserve, International Review of Electrical Engineering (I.R.E.E.), Vol. 13, No. 3 May-June 2018

[5] M. Kuivaniemi, H. Uimonen, "Uusi nopea taajuusreservi Fast Frequency Reserve FFR", Presentation, Fingrid Inc., 8.5.2019.

[6] Fingrid Open Data. The price of consumption imbalance electricity. https://data.fingrid.fi/en/dataset/the-price-of-comsumption-imbalance-electricity

[7] Energy Authority, 2018, "National Report 2018 to the Agency for the Cooperation of Energy Regulators and to the European Commission.