A methodology for electricity retailer short-term profit optimization in a smart grid environment

Abstract

Liberalization of electricity markets has changed the nature of the electricity retail business. In addition to market conditions, changes in the operational environment have considerable impact. The development of smart grids may thus be an agent for the next major changes in the electricity retail business. Smart grids, although offering electricity retailers considerable potential to improve the profitability of their business, also create new risks. This paper examines possible impacts of the development of smart grids on the electricity retail business and presents a methodology for electricity retailer short-term profit optimization in the current operational environment and in a future hypothetical smart grid environment. The profit optimization strategies for both operational environments are determined based on theoretical and comparative analysis, illustrated using Nordic electricity markets as an example market area, and demonstrated using a case example. It is found that smart grids offer new functionalities, of which particularly the utilization of distributed energy resources (DER) provides great potential for retailers to improve their profitability in short-term markets.

1 Introduction

It is typical of deregulated electricity markets that profit margins in the retail business are low, but the risks relatively high. One of the main reasons for the heightened risks has been the disconnection between the wholesale and retail markets [1]. Electricity is sold to most retail customers at fixed rates but electricity procurements on wholesale markets are made at a changing price, which exposes retailers to price risk. Price risk, together with the volume risk caused by retailers' load obligations, which oblige retailers to provide customers with the energy needed to cover their consumption (loads), forms a significant cost risk. Typically, retailers' risks can be only partially eliminated by hedging. Moreover, hedging incurs costs, and over-hedging should thus be avoided.

Such a business environment clearly indicates a need for tools to address profit optimization. Technological development, including smart grids, provides conditions in which such tools can be developed. The increasing amount of DER including customer load controls, energy storages and distributed generation, and the development of sophisticated control applications, in particular, offer a range of opportunities for electricity market parties, including retailers, to enhance profit optimization.

In the literature, studies relating to the profit optimization of electricity retailers/traders typically focus on long-term or mid-term electricity procurement planning and portfolio optimization [2-5], determination of risk premiums and electricity sales prices [6-9], and evaluation of optimal bidding strategies [10-11]. Some studies consider the possibility of utilizing demand response (DR), distributed energy resources, or other related methods to improve profitability [12-19]. Among these studies many different approaches and techniques can be found for the modeling of the electricity retailer profit optimization problem. For instance, recent research has considered mid-term power portfolio optimization with risk assessment [2], electricity procurement of large consumers approached using the concept of information gap decision theory [3], medium-term risk management and sales price determination based on a decision-making framework [4], and a bi-level programming approach to mid-term decision-making [5]. Typical approaches also include consideration of uncertainties related to electricity price and consumption in order to define an optimal procurement strategy [6], risk premium [8] or electricity sale price [17].

Approaches for evaluating and modeling of risks in the literature include a model for evaluating sales contract maturity risk [7], a framework to quantify risks related to wholesale electricity contracts by using RAROC methodology [9], a method for optimal retailer bidding in a day-ahead market considering risk and electricity demand [10], and a model for consideration of profit risk using shortfall costs [11]. A summary of risk assessment in energy trading [12] and a decision support tool that aims to optimize the provision of residential energy services [13] has been presented also.

The impact on energy trading of improved demand response and the increase in DER has been considered, for instance, by the presentation of a demand response simulator that allows study of response actions [14], the introduction of a demand response model for the purpose of representing customer response to time-based and incentive-based demand response programs [15], and the use of a stochastic programming approach for trading wind energy in a market environment under uncertainty [16]. In addition, electricity retailer profit optimization in different operational environments [18] as well as the business potential of customer load control in an electricity retailer's short-term profit optimization [19] has been considered in recent studies.

Even though different techniques and approaches are used, common features and deficiencies can be identified. Evaluation and modeling of volume and price risk plays a central role in most models. On the other hand, it is not typically clearly addressed how market and operational environment impacts the retailer's ability to maintain profitability. In addition, the examined literature concentrates mainly on long-term and mid-term planning, and only few studies consider the possibility of improving retailers' profitability in short-term markets by trading and utilizing controllable DER.

This study contributes to the literature by presenting an approach that considers the impacts of operational environment and the possibilities of utilizing DER. The paper presents theoretical analysis of the most important factors having an impact on retailers' profitability and a basic model for retailer short-term profit optimization in Nordic electricity markets. The model is also demonstrated by using a case example. The retailer profit optimization model and strategies are constructed based on comparative analysis of different operational environments and their distinctive features.

The rest of the paper is organized as follows: Section 2 discusses market and operational environments; Section 3 describes the profit optimization problem; Section 4 presents profit optimization strategies; Section 5 introduces a case study; and the results are discussed in the concluding section 6.

2 Market and operational environments

Pertinent features of the market and operational environment have to be analyzed before retailer's profit optimization strategies can be developed. This chapter examines the electricity retail business in the current operational environment in Nordic markets, and considers its future development.

2.1 Planning of electricity procurements

Minimization of risks is one of the prerequisites of a profitable retail business. An essential part of risk management is long-term planning (from days to years), which involves ensuring electricity procurements at fixed prices in the wholesale markets, for instance, by setting up contracts with suppliers and hedging using financial instruments. Figure 1 illustrates the segmentation of electricity retailer profit optimization into short-term and long-term profit optimization in the Nordic markets.

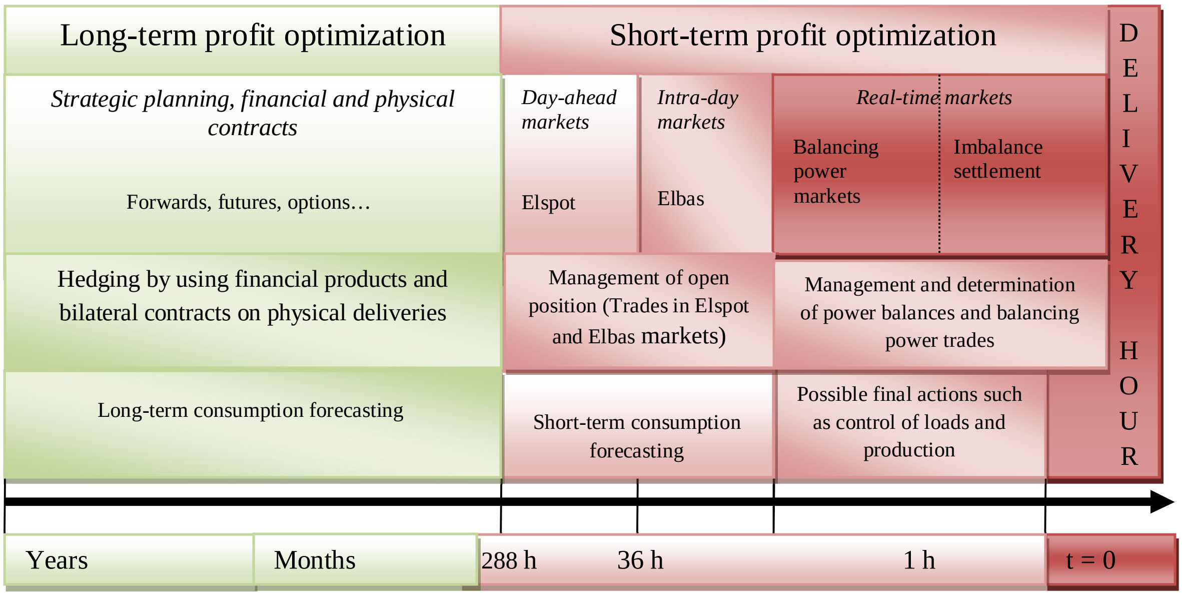

Figure 1. Segmentation of electricity retailer profit optimization [18]

The long-term planning assessments determine retailers' needs for balancing trades in short-term markets, and other possible operations such as control of production or loads prior to the delivery hour. In practice, however, some difference almost always exists between a retailer's forecasted and actual consumption, and the retailer's electricity procurements do not match actual consumption precisely. The difference between a retailer's secured electricity procurements in advance and expected electricity sales in retail markets is called an *open position*. The manner in which a retailer succeeds in managing its open position prior to the delivery hour has considerable impact on the retailer's profits [18, 19].

2.2 Current operational and market environment

Important markets for physical exchange of electricity in Nordic electricity markets include spot markets organized by Nordpool Spot and balancing (regulating) power markets organized by the system operators. The spot markets consist of the Elspot and Elbas markets. In the Elspot market, market participants can trade hourly power contracts for the next day 24-hour period, 12-36 hours ahead, and in the continuous intra-day Elbas market until one hour prior to delivery. [20] Elbas can be used as an alternative to the balancing market for all or some of the imbalance that a market player may have after making day-ahead trades. After Elbas trading has closed, balancing trades can no longer be conducted. Final power balances of the market players are determined through an imbalance settlement procedure.

Each party operating in the electricity market is responsible for management of its own power balance between electricity production/procurement and consumption/sales. For instance, Fingrid, the Finnish System Operator (SO), obliges that the market parties has to plan and control their electricity procurements in a way that the power imbalance can be maintained at an appropriate level with respect to the extent of the operation of the party [21]. In practice, a market party requires an open supplier who is responsible for maintaining the precise power balance of the party [21]. A party whose open supplier is a SO is referred as the *balance responsible party*.

Prices for balancing power serve as the basis for the pricing of imbalance power, which is the electric energy used to cover the balance deviation accruing to a party during a specific hour. The balance service model applied in the Nordic markets is referred to as a model of two-balances. In this model, generation is allocated to one balance, and consumption, purchases and sales to the other. A two-price system is applied to the balance deviation in the production balance, and a one-price system to the balance deviation in the consumption balance. In the two-price system, separate prices are calculated for the sales and purchases of imbalance power. In the one-price system, the purchase and sale price of imbalance power are the same. The purchase price of imbalance power is the price at which Fingrid purchases electricity from the balance responsible party, and the sale price of imbalance power is the price at which the balance responsible party purchases electricity from Fingrid. [21]

Prices of balancing power, both up-regulating and down-regulating power, are determined based on the regulations of the Nordic balancing power markets and the bids of market players. Table 1 illustrates price formation for imbalance power.

Table 1. Price formation for imbalance power

	Direction of the regulation	**Purchase price of imbalance power**	**Sale price of imbalance power**
Production balance	up	Elspot Fin	up-regulation price
	no regulation	Elspot Fin	Elspot Fin
	down	down -regulation price	Elspot Fin
Consumption balance	up	up-regulation price	up-regulation price
	no regulation	Elspot Fin	Elspot Fin
	down	down-regulation price	down-regulation price

In addition to energy payments, market players participating in balancing power markets have to pay balance service payments consisting of fixed monthly payments and production, consumption and volume fees. The aforementioned fees can be viewed as “penalties” for market players that cannot maintain power balances. Consequently, the avoidance of extra balancing power fees has an important role in market players business.

2.3 Smart grid environment

The precise nature of the future smart grid environment is not known, studies [18, 22, 23] generally agree however that the smart grid architecture of the future will be based on two-way data transfer, sophisticated automation and control systems, and an increasing amount of DER with controllable loads, distributed generation and energy storages. Such a smart grid environment would enable a variety of new functionalities, and thus provide new opportunities to improve the efficient use of energy and power systems.

The future smart grid environment is described in this paper using the concept of an interactive customer gateway, which is presented in Figure 2 and described in detail in [23].

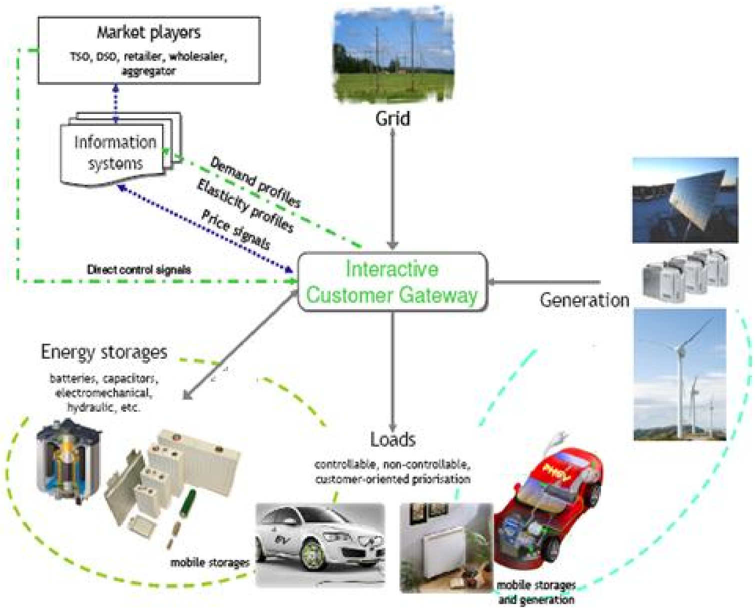

Figure 2. The concept of an interactive customer gateway. [23]

The basic idea underlying this concept is that the development of smart grids makes possible a new kind of interactive customer gateway in which real-time and two-way data transfer connections permit flexible interactions between different market players and customers. This creates an infrastructure allowing control of customer loads, energy storages and distributed generation.

3 Profit optimization problem

Examination of the market and operational environment provides basis for planning of retailer profit optimization. In this chapter, the electricity retailer's profit optimization problem is examined in more detail in the current operational environment and in the smart grid environment, and a basic mathematical model describing the electricity retailer's short-term profit optimization problem is presented.

3.1 Problem assumptions

To simplify the analysis and to address the retailer's short-term profit optimization problem in the Nordic electricity markets, some basic assumptions are made. First, it is assumed that the retailer under study sells electricity to its customers at fixed rates and trades electricity in the Nordic spot markets and through the imbalance settlement (imbalance power). Secondly, it is assumed that the retailer has secured a fixed price for most of its electricity procurements by long-term/mid-term hedging. This hedging reduces the retailer's risks in short term markets, but does not eliminate it totally. Consequently, the retailer faces the following risks in the short-term markets;

- Price risk: Caused by the variation of electricity price
- Volume risk: Caused by the variation in customers' consumption
- Imbalance risk: Caused by the power imbalance

It is assumed that in the current operational environment the retailer's open position and resulting power imbalance can be managed only by trading in the spot markets, but in the smart grid environment also by utilizing controllable DER. This includes the assumption that the smart grid provides an environment in which retailers can own or purchase DER capacity for their use.

It is reasonable to assume that retailers operating in the Nordic markets do not have significant market power, and can be considered as price takers. In other words, it is assumed that the retailer cannot impact on electricity prices by its own bidding actions, and other market participants have no significant impact, through bidding actions or other operations, on the retailer in question.

3.1 Problem formulation

The aim of the electricity retailer is to maximize its expected profits in a specific time interval. An electricity retailer's profits on the power markets depends on the energy sold on the retail markets E_{sell}, the electricity retail sales price ρ_{sell}, energy purchased on the wholesale markets E_{buy}, and the price of purchased electricity on the wholesale markets ρ_{buy}. Thus, the maximum profits at the time interval t = 0…T are

$$max \int_0^T profits(t)dt = max \int_0^T \left(\rho_{sell}(t) * E_{sell}(t) - \rho_{buy}(t) * E_{buy}(t)\right) dt. \qquad (1)$$

3.1.1 Profit optimization in the current operational environment

In the current operational environment, the retailer cannot utilize controllable DER and thus the retailer's short-term electricity procurements prior to the delivery hour are made on the power exchange. In addition, the retailer may have to trade imbalance power to maintain its power balance. In this case, the retailer's maximum profits at the time interval 0…T can be expressed as

$$max \int_0^T profits(t)dt = max \int_0^T \begin{pmatrix} \rho_{sell}(t) * E_{sell}(t) - \rho_{spot}(t) * E_{spot}(t) - \\ \rho_{elbas}(t) * E_{elbas}(t) - \rho_{reg}(t) * E_{reg}(t) \end{pmatrix} dt, \qquad (2)$$

where ρ_{spot} is the Elspot price, ρ_{elbas} the Elbas price, ρ_{reg} the price of the imbalance power including balance power fees, E_{spot} energy traded in the Elspot market, E_{elbas} energy traded in the Elbas market, and E_{reg} the amount of traded imbalance power.

In the short-term markets, the retailer cannot influence the amount or price of the sold energy by its own actions and thus the parameters ρ_{sell} and E_{sell} can be regarded as exogenous. Thus, the retailer's profit optimization problem can be turned into the form of an electricity procurement cost minimization problem, expressed by the equation

$$C_{min} = min \int_0^T \begin{pmatrix} (\rho_{spot}(t) * E_{spot}(t) + \rho_{elbas}(t) * E_{elbas}(t) + \\ \rho_{red}(t) * E_{reg}(t) \end{pmatrix} dt, \qquad (3)$$

where C_{min} is the retailer's minimum electricity procurement costs.

The examined retailer is a price taker and consequently the parameters ρ_{spot}, ρ_{elbas} and ρ_{reg} can be regarded as exogenous. Now, the only non exogenous variables in the equation (3) are the amounts of purchased energy on different power markets. Thus, it can be concluded that in theory, in order to maximize profits, the retailer should aim to make its electricity procurements on the Elspot or Elbas market, or trough imbalance power trades, depending on where it can purchase the electricity needed at the lowest price. In practice, the limitations for trading set by the markets and SO have to be considered also.

3.1.2 Profit optimization in a smart grid environment

According to the basic hypothesis of this paper, in a smart grid environment, the electricity retailer can utilize controllable DER to manage its electricity procurements and open position. Now, the electricity retailer profit optimization problem in the smart grid environment can be expressed as an electricity procurement cost minimization problem by the equation

$$C_{min.} = min \int_{o}^{T} \begin{pmatrix} (\rho_{spot}(t) * E_{spot}(t) + \rho_{elbas}(t) * E_{elbas}(t) + \\ \rho_{reg}(t) * E_{reg}(t) + \rho_{DER}(t) * E_{DER}(t) \end{pmatrix}. \qquad (4)$$

where ρ_{DER} is the DER utilization cost and E_{DER} the amount of energy controlled by utilization of DER. E_{DER} consists of E_{al}, E_{ag} and E_{es}, which present respectively the energy controlled by using active (controllable) loads, energy controlled by using active (controllable) generation, and energy controlled by using energy storages. Now, the retailer's minimum electricity procurement costs can be written in the form

$$C_{min} = min \int_{0}^{T} \begin{pmatrix} (\rho_{spot}(t) * E_{spot}(t) + \rho_{elbas}(t) * E_{elbas}(t) + \rho_{reg}(t) * E_{reg}(t) \\ +\rho_{ag}(t) * E_{ag}(t) + \rho_{al}(t) * E_{al}(t) + \rho_{es}(t) * E_{es}(t), \end{pmatrix} \qquad (5)$$

where ρ_{ag} is the utilization cost of active generation, ρ_{al} the utilization cost of active loads, and ρ_{es} the utilization cost of energy storages.

By its own actions, the retailer cannot impact on the variables ρ_{al}, ρ_{ag} and ρ_{es} as regards short-term profit optimization and thus they are exogenous. Consequently, electricity prices in different markets and the cost of utilization of different active energy resources determines the optimal profit optimization strategy in each case.

3.1.3 Price elasticity

Transition towards smart grid environment involves many changes, such as increase of intermittently renewable generation, which may have high impact on electricity prices. Thus, it is important to consider price elasticity when planning a retailer's profit optimization in a smart grid environment.

Price elasticity describes the impact of electricity demand (consumption) on electricity price. When all prices and quantities have been normalized respect to a given equilibrium point, price elasticity can be expressed by equation

$$\varepsilon = \frac{\Delta q}{\Delta \rho}, \qquad (6)$$

where q is quantity of electricity (demand) and ρ price of electricity.

Although operation of a single retailer does not typically have significant impact on wholesale market prices, in a larger scale the changes of electricity demand, resulted in for instance on large-scale DR programs, may have considerable impact on electricity prices.

4 Profit optimization strategies

Maximization of a retailer's profits in the short-term markets requires management of the open position based on the prevailing market situation. In the current operational environment, retailers are limited to trades on the short-term markets, but in a future smart grid environment DER controls can additionally be used. This chapter proposes the use of different short-term profit optimization strategies in different operational environments.

4.1 Profit optimization strategy for current operational environment

In section 3.2.1, it was concluded that the retailer should aim to make its electricity procurements on the market where it can purchase the energy needed at the lowest price. However, in practice, the limitations for trading set by the markets and SO must be considered also. In addition, imbalance power prices are known only after the delivery, as well as customers' actual consumption, which complicate the determination of optimal electricity procurement strategy.

The forecasting of future electricity prices is a challenging task and the reliability of existing price forecasting techniques can be regarded to be too low to provide a solid base for risk taking profit optimization planning. Future electricity consumption, however, can be typically forecasted with higher accuracy based on the customer load profiles and weather forecasts. Still, consumption forecasting, just like price forecasting, always involves uncertainty and forms a meaningful risk for the retailer. [18] In addition, in some cases, the retailer cannot hedge against price variations in short-term markets. For instance, if electricity prices are high in all short-term markets, the retailer may be forced to buy high-priced electricity in any case.

In addition to minimization of risks, the retailer aims to maximize its expected profits. As noted earlier, to maximize profits the retailer should aim to make its electricity procurements at the lowest possible price. In the spot markets, either the Elspot or Elbas price can be lower, depending on the hour. The pricing of the imbalance power, however, is more complicated and requires more detailed examination.

In the production balance, a two-price system is applied and consequently trading of production imbalance power always causes greater costs to the retailer than if corresponding electricity trades had been made in the Elspot market. Therefore, in an optimal situation, the retailer would have no imbalance in the production balance. However, if the retailer does have a power imbalance, the direction of the retailer's imbalance, direction of the regulation during the hour, and the price of production imbalance power determine resulting extra costs. To minimize the extra costs, the retailer should rather have a small surplus than a deficit on its electricity procurements during the up-regulation hour, and rather a small deficit than surplus during the down-regulating hour.

In the consumption balance, a one-price system is applied, and thus, the sale and purchase prices of the imbalance power are always the same. Consequently, it can, in some cases, be beneficial for the retailer to have an imbalance in the consumption balance. However, this requires that the imbalance is "in the right direction". More precisely, the retailer should have surplus on energy procurements when the price of consumption imbalance power is higher than the corresponding spot price, which will provide a profitable "sell back" opportunity. When the price of consumption imbalance power is lower than the corresponding spot price, the retailer should have a deficit on electricity procurements, since it can purchase imbalance power at a lower price than energy in the Elspot market. However, if the retailer's imbalance is in the wrong direction in the preceding cases, the retailer will suffer losses instead of making profits.

Based on the description above, the uncertainty related to future electricity prices and customers' consumption, and the retailer's limited opportunities for managing its open position immediately prior to the delivery hour, it is proposed that the retailer should, in the current operational environment, use a risk avoiding strategy for its short-term profit optimization. One solution for the minimization of risks is that the retailer aims to minimize the size of its open position prior to the delivery hour. In this way, the retailer can relatively simply minimize the risk related of being in imbalance.

Even though this risk avoiding profit optimization strategy will not provide maximum profits in all cases, the realization of risks in more risk taking profit optimization strategy could result in considerable extra costs for the retailer. In addition, the basic risk avoiding strategy, in many cases, provides the maximum profits. This is true assuming that $\rho_{spot} < \rho_{elbas} < \rho_{reg}$. In this case, the retailer's theoretical minimum electricity procurement costs that provides the maximal profit at the time interval 0…T are

$$C_{min} = \int_0^T E_{load}(t) * \rho_{spot}(t), \quad (7)$$

where E_{load} is the energy needed to cover the retailer's total loads during the hour t.

4.2 Profit optimization in a smart grid environment

The development of a smart grid environment enhances the ability of retailers to utilize controllable DER and more effective forecasting tools. This enables retailers to operate and manage their open positions more flexibly, and gives more options for profit optimization in short-term markets.

This chapter presents the main principles for retailer short-term profit optimization in a smart grid environment, and utilization of controllable DER in this task. The qualitative principles of active management of an open position and control of DER will be introduced, and an example scenario on execution of DER control presented.

4.2.1 Principles of active management of open position

Active management of the open position is based on the idea that the retailer continuously manages the open position by trading in the markets and controlling available DER capacity. In a smart grid environment, two-way data transfer allows retailers to access real-time measurement data on different variables. This and other external data can be used to develop more accurate and reliable consumption and price forecasting applications, based on which retailers can manage their open positions close to the delivery utilizing DER controls. This improves the ability of retailers to hedge against risks and use new profit optimization strategies.

In the Nordic market, as in many other markets, there can be high variation in electricity prices. While typical hourly prices are tens of Euros per megawatt hour, peak prices can rise to hundreds of Euros per megawatt hour, or even higher. Consequently, the electricity price can be regarded as the main input in active management of an open position, although estimations of future electricity consumption also play an important role.

In section 4.1, it was concluded that the retailer should aim to avoid trading of production imbalance, but in the consumption balance imbalance power trades can increase a retailer's profits. The retailer should also aim to make its electricity procurements on the market where it can purchase the electricity needed at the lowest price. In case that price between different markets varies significantly and assuming that the retailer has clear indications of the level of electricity prices on different markets, to maximize profits the retailer should manage its open position in the consumption balance based on the principles presented in Table 2.

Table 2. Qualitative principles for the management of a retailer's open position in the consumption balance when electricity price between different markets varies

Spot price	Price of consumption imbalance power	Price difference between consumption imbalance power and spot price	Optimal direction of open position
High / Average	Low	Negative	Deficit on electricity procurements
Average	Average	No difference	No imbalance
Low / Average	High	Positive	Surplus on electricity procurements

Based on Table 2, it can be concluded that if the price of consumption imbalance power is lower than the spot price, the retailer should aim to have a deficit on its electricity procurements. If the reverse is true, the retailer should aim to have a surplus on its electricity procurements. In cases that there is no significant difference between the prices, the retailer should aim to minimize the open position to avoid the extra cost caused by balance power fees.

In many cases, unusually high or low electricity prices exist in the different markets at the same times. In such cases, the retailer cannot hedge against high (or low) prices by making trades in different short-term markets. However, the possibility to manage an open position by controlling DER provides an opportunity to hedge against high (or low) prices and achieve greater profits also in these cases. Table 3 presents the principles for management of open positions in consumption balance using DER controls for cases that market prices are at the same level in different markets.

Table 3. Qualitative principles of the management of an open position and control of DER when electricity prices are at the same level in different markets.

Electricity prices at the markets	Load control actions	Production control actions	Energy storage control actions	Optimal direction of open position
Low	Loads on	Reduce production	Charge	Deficit on electricity procurements
Average	No actions	No actions	No actions	No imbalance
High	Loads off	Increase production	Discharge	Surplus on electricity procurements

It can be seen from Table 3 that if electricity prices in the markets are low, the retailer should aim to have a deficit on its electricity procurements, increase loads, reduce production and charge energy storages. If the reverse is true, the retailer should aim to have a surplus on electricity procurements, decrease loads, increase production and utilize stored energy. When electricity prices on the markets are at the average level, the retailer should aim to minimize the open position in order to avoid the extra costs caused by balance power fees and control actions.

Based on above discussion, it can be concluded that the retailer can improve its profitability in the smart grid environment by actively managing its open position following the principles introduced. However, this requires that the retailer has knowledge or adequately accurate forecasts of electricity consumption and prices in the markets.

4.2.2 Control of DER

In a smart grid environment, the retailer can get relatively real-time measurement data on different variables such as electricity consumption and production. This information improves the retailer's ability to create accurate forecasts of future electricity consumption and prices, and provides a basis for the planning of trades and control actions needed for profit maximization.

Optimized control of DER is a complex process and requires inputs and outputs on many variables. Figure 3 presents an example scenario of control of DER as part of short-term profit optimization in a smart grid environment. In this scenario, it is assumed that the retailer can use controllable DER in such a way that the market model, or other external factors do not impose significant limits.

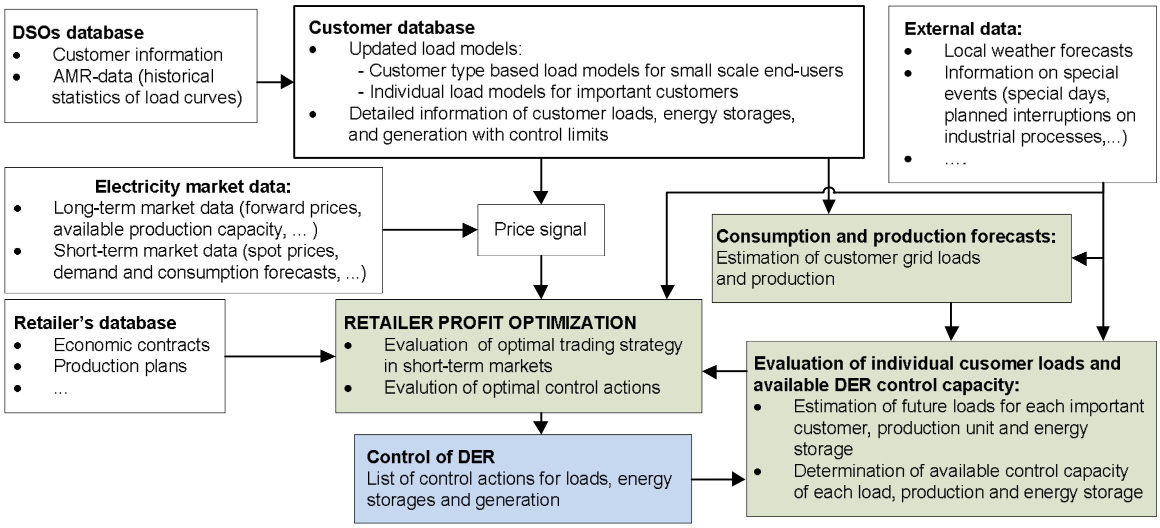

Figure 3. Scenario for utilization of DER in a smart grid environment. [18]

From Figure 3 it can be seen that many inputs and subtasks are needed before a retailer can determine and execute the optimal control actions. Acquisition of adequately real-time data on customer loads, energy storages and distributed generation is required to guarantee that control actions can be realized with good reliability and without extra delays. AMR data on customers' consumption provides important information, based on which customers load models can be updated or individual load models for important customer created. Load models and local weather forecasts in turn provide a basis for consumption and production forecasts and the estimation of future grid loads and production. Based on these estimations and electricity price signals, the optimal strategy for trades and control actions can be determined and requisite DER controls executed.

5 Case study

This case example illustrates the use of DER controls and active management of retailer's open position in a smart grid environment, and evaluates its impact on a retailer's profits. An optimization model was built for the calculation of theoretical saving potential that the hypothetical DER control potential can provide for the retailer under examination. The calculation of saving potential within the time period of 1 Oct. 2011 – 31 March 2012 is made by using actual electricity sales data of a Finnish retailer and historical electricity prices.

The baseline for retailer short-term electricity procurement costs is calculated assuming that the retailer cannot use controllable DER, which illustrates a typical situation in the current operational environment and the use of a risk avoiding profit optimization strategy. The impact of DER controls on the retailer's profits in a smart grid environment is evaluated in two different scenarios. In scenario one DER controls are made based on spot prices. Because spot prices are known in advance, the retailer's risks are rather low in this scenario. In scenario two, the impact of DER controls on the retailer's profits are calculated based on the historical consumption imbalance power prices. This illustrates the use of more risk taking profit optimization strategy, in which the retailer's open position is actively managed based on the prevailing market situation. In practice, however, imbalance power prices are known only after the delivery, and thus, it should be borne in mind that results of this scenario shows the theoretical maximum saving potential.

To keep the case examination illustrative and simple, some basic assumptions and simplifications are applied, including the assumptions introduced in section 3.1. The retailer's hypothetical DER control capacity is estimated based on the data of the retailer's total sales to residential retail customers' and the data of the Finnish households' electricity usage study [24]. A detailed description from the methodology used for the evaluation of DER control capacity can be found in [19]. The retailer's hypothetical DER control capacity consists of the retail customers' aggregated water heating and direct electric heating loads. The estimated load control response, when a load control command is given by the retailer, approximates 10 % of the retailer's hourly sales to the residential retail customers. Limitations on the load control set by the customers' comfort is taken into account by setting the maximum continues disconnection of loads to one hour during the permissible control periods, 6 to10 a.m. and 17 to 21 p.m.

Used optimization model determines the optimal load control time within each control period, and calculates the effect of the load control on the retailer's profits. Results are presented in Fig. 4, 5 and 6, and in Table 4. Fig. 5 and 6 presents the same results, but the graph in Fig. 6 has been made more illustrative by setting the maximum y-axis value to 4000.

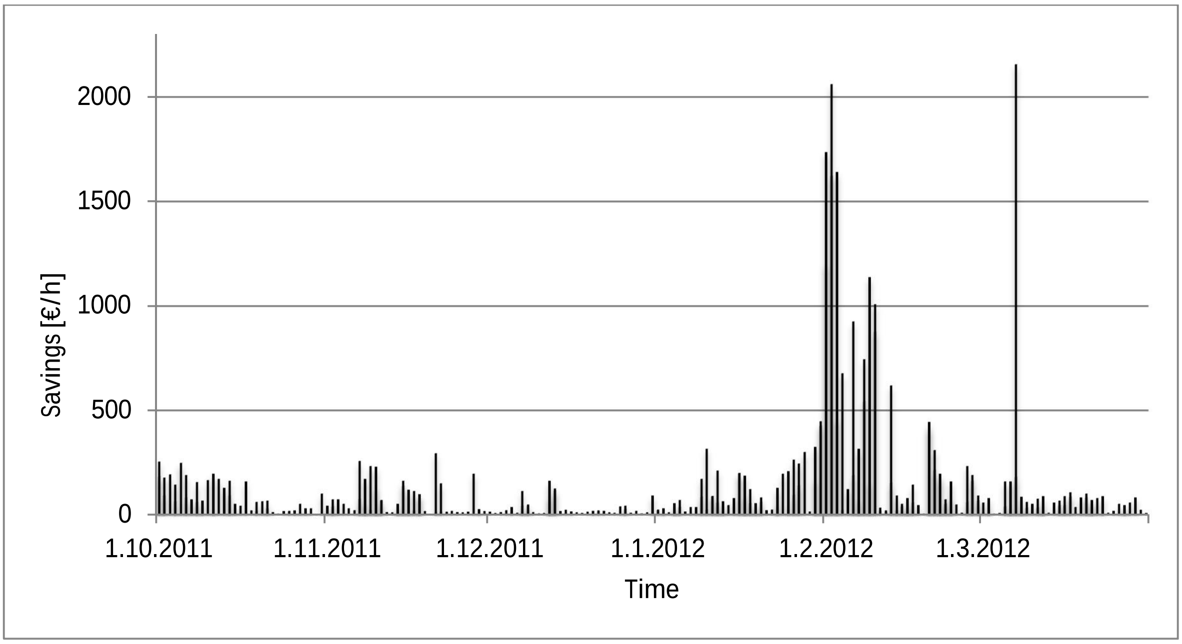

Figure 4. Saving potential for optimized load control based on spot prices

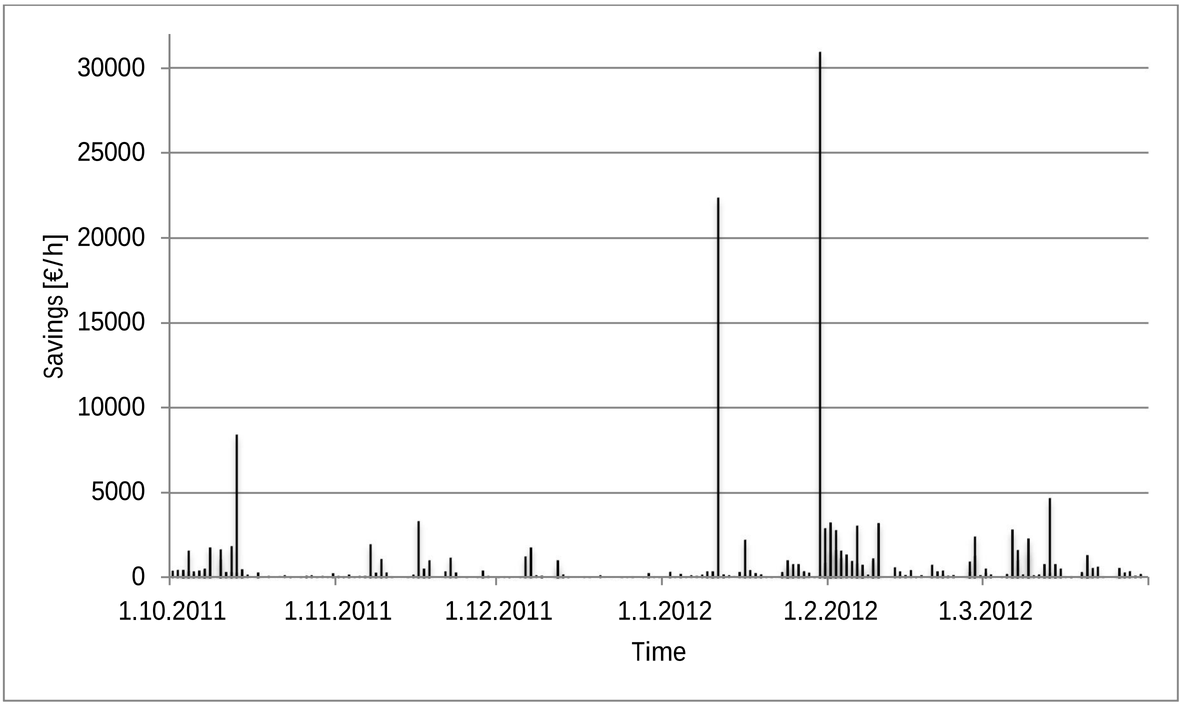

Figure 5. Saving potential for optimized load control based on consumption imbalance power prices

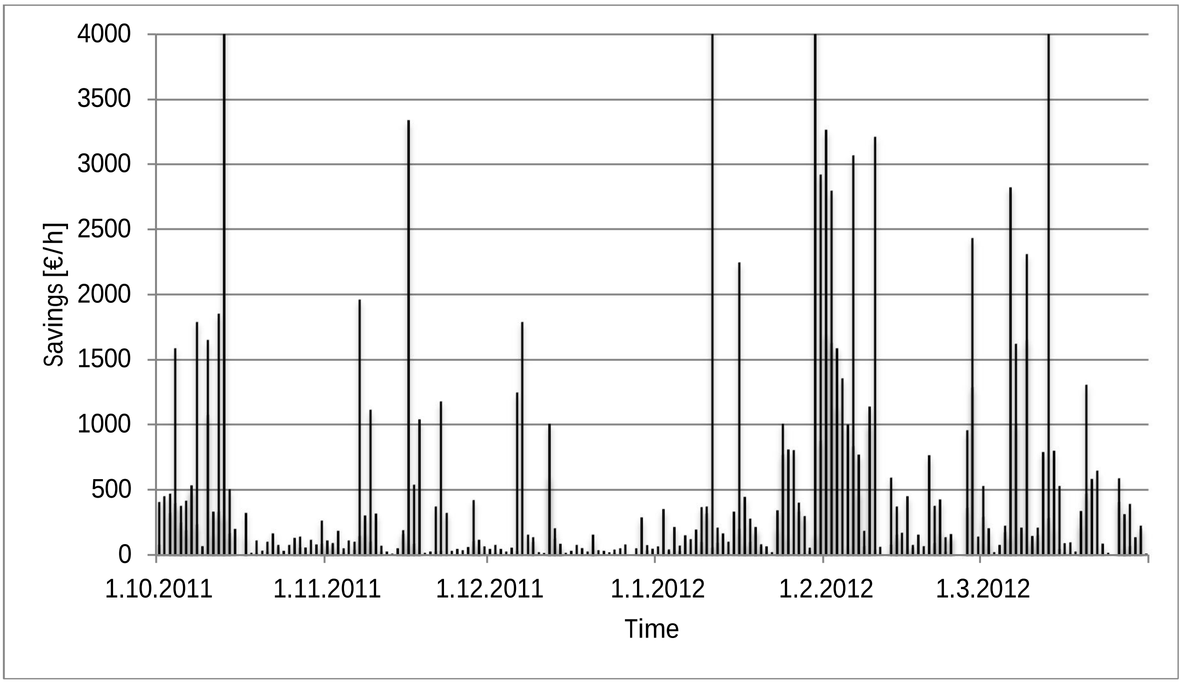

Figure 6. Saving potential for optimized load control based on consumption imbalance power prices, zoomed figure. (Y-axis values is limited to 4000)

Fig. 4 shows saving potential within each control period in scenario one, and Fig. 5 and 6 in scenario two. The highest hourly saving potentials in both scenarios can be found during February, because cold weather increased the variation in prices providing higher saving potential for the load control. Table 4 presents the characteristics parameters describing the effects of load control in both scenarios.

Table 4. Optimization results

	Scenario 1: Load control based on spot prices	**Scenario 2: Load control based on consumption imbalance power prices**
Total savings [€]	39825	178117
Average savings [€/h]	236	545
Highest saving [€/h]	2157	30923
Highest sifted energy during one hour control [MWh/h]	18,8	18,6
Lowest sifted energy during one hour control [MWh/h]	7,3	7,4

Table 4 shows the retailer can achieve savings in both scenarios, if load controls can be put in practice with low costs. However, load control based on the consumption imbalance power prices provided over four times higher saving potential than load control based on spot prices. Total saving potential in scenario one was approximately 40000 € when sifted energy usage varied 7.3 to 18.8 MWh/h, and in scenario two 178 000 € when sifted energy varied 7.4 to 18.6 MWh/h. This indicates that active management of open positions could be an effective way to improve retailers short-term profit optimization in a smart grid environment, although it includes higher risks than load control based on spot prices.

6 Conclusions

A methodology for electricity retailer short-term profit optimization in the current operational environment and in a smart grid environment was introduced in this paper. In addition, strategies for retailer short-term profit optimization in these operational environments were presented, and validated by using a case example.

In the current operational environment, the ability of retailers to manage the risks in short-term markets is more limited than in a smart grid environment. Thus, the use of a risk avoiding profit optimization strategy, in which the retailer aims to minimize the size of the open position when the delivery hour approaches, was recommended.

In a smart grid environment, the retailer can access real-time data, for instance, on electricity consumption and production. By utilizing this data, the retailer can improve the accuracy of electricity consumption and price forecasts, and thus operate more flexible based on the changing market situations. Thus, the use of more risk taking profit optimization strategy, which base on the active management of an open position, was proposed.

The introduced methodology and strategies for retailer profit optimization was illustrated, and the saving potential provided by the utilization of DER for the retailer evaluated, by using a case example. The total estimated saving potential for load control based on imbalance power prices during the six month examination period was close to 180 000 €, and the highest saving potential for single one hour load shift during electricity price peak over 30 000 €. Although the cost of the load control was not considered in the examination, these results shows that in the best case active management of open position by utilizing DER controls can permit retailers' to benefit from price fluctuations, and provide considerable saving potential in the long run.

When considering the results of the case example some practical details should be taken into account. Results of the case example are calculated based on historical price and consumption data, and introduced scenarios include many assumptions. Therefore, the results involve some uncertainty. In particular, the amount of the retailer's estimated load control capacity may include significant uncertainty, because, in practice, it varies depending on many different factors. Moreover, uncertainty related on electricity consumption and price, market models and other such factors set limitations for retailers operation, and make it challenging to exploit the whole saving potential in practice. In addition, the cost of load control should also be considered in more detail in practice. However, more detailed consideration of preceding factors inquires further research, and is outside the scope of this study.

In any case, the introduced methodology and strategies for retail short-term profit optimization in a smart grid environment was shown to be functional. The case examination also indicated that utilization of DER in a smart grid environment can provide saving potential for the retailer. Finally, it can be concluded that an active management of the retailer's open positions based on the reliable electricity consumption and price forecasts can offer a new tool for retailers to improve profitability of their business in a future smart grid environment.

Acknowledgement

"This work was carried out in the Smart Grids and Energy Markets (SGEM) research program coordinated by CLEEN Ltd. with funding from the Finnish Funding Agency for Technology and Innovation, Tekes."

References

[1] D. Caves, K. Eakin and A. Faruqui, Mitigating price spikes in wholesale markets through market-based pricing in retail Markets, *Electricity Journal*, Vol.13, Issue 3, pp.13-23, 2000

[2] J. Xu, P.B. Luh, F.B.White, E.Ni and K. Kasiviswanathan, power portfolio optimization in deregulated electricity markets with risk management, *Electric Power Systems Research*, Vol. 77, Issue 8, pp. 1000-1009, June 2007

[3] K. Zare, M.P. Moghaddam and M.K. Sheik-El-Eslami, Risk-based electricity procurement for large customers, *IEEE Transactions on Power Systems*, Vol. 26, No. 4, pp.1826-1835, March 2011

[4] A. Hatami, H. Seifi and M.K. Sheikh-El-Eslami, A stochastic-based decision-making framework for an electricity retailer: Time-of-use pricing and electricity portfolio optimization, *IEEE Transactions on Power Systems*, Vol. 26, Issue 4, pp.1808-1816, February 2011

[5] M.Carrión, J.M. Arroyo and A.J. Conejo, A bilevel stochastic programming approach for retailer futures market trading, *IEEE Transactions on Power Systems,* Vol. 24, Issue 3, pp. 1446-1456, August 2009

[6] A.R. Hatami, H.Seifi and M.K Sheikh-El-Eslami, Optimal price and energy procurement strategies for a retailer in an electricity market, *Electrical Power System Research*, Vol.79, Issue 1, pp. 246-254, January 2009

[7] L. Bartelj, D.Paravan, A. F. Gubina and R. Golob, Valuating risk from sales contract offer maturity in electricity market, *International Journal of Electrical Power and Energy System,* Vol. 32, Issue 2, pp. 147-155, February 2010

[8] L. Bartelj, A.F. Gubina, D. Paravan and R. Golob, Risk management in the retail electricity market: The retailer's perspective, *Power and Energy Society General Meeting*, IEEE, Minneapolis 2010

[9] M. Prokopczuk, S.T. Rachev, G. Schindlmayr and S. Trück, Quantifying risk in the electricity business: A RAROC-based approach, *Energy Economics,* Vol. 29, Issue 5, pp. 1033-1049, September 2007

[10] M. Hajati, H. Seifi and M. K. Sheikh-El-Eslami, Optimal bidding strategies in a DA market – a new method considering risk and demand elasticity, *Energy*, Vol.36. Issue 2, pp. 1332-1339, February 2011

[11] S.-E. Fleten and E. Pettersen, Constructing bidding curves for a price-taking retailer in the Norwegian electricity market, *IEEE Transactions on Power Systems,* Vol. 20, Issue 2, pp. 701-708, May 2005

[12] R. Dahlgren, C.C. Liu and J. Lawarrée, Risk assessment in energy trading, *IEEE Transactions on Power Systems,* Vol. 18, Issue 2, pp. 503-511, May 2003

[13] M.A.A. Pedrasa, T.D. Spooner and I.F. MacGill, A novel energy service model and optimal scheduling algorithm for residential distributed energy resources, *Electric Power System Research*, Vol. 81, Issue 12, pp. 2155-2163, December 2011

[14] P. Faria and Z. Vale, Demand response in electrical energy supply: An optimal real time pricing approach, *Energy*, Vol. 36, Issue 8, pp. 5374-5384, August 2011

[15] S. Yousefi, M.P. Moghaddam and V.J. Majd, Optimal real time pricing in an agent-based retail market using a comprehensive demand response model, *Energy*, Vol. 36, Issue 9, pp. 5716-5727, September 2011

[16] H.M.I. Pousinho, V.M.F. Mendes and J.P.S. Catalão, A risk-averse optimization model for trading wind energy in a market environment under uncertainty, *Energy*, Vol. 36, Issue 8, pp. 4585-5424, August 2011

[17] L. Coslovich, R. Pesenti, G. Piccoli and W. Ukovich, A model for setting and validating sale prices of an electricity trader by means of load shifts, *International Journal of Energy Sector Management*, Vol. 2 Issue 3, pp.351 – 367, 2008

[18] P. Valtonen, J. Partanen and S. Honkapuro, Electricity retailer profit optimization in different operational environments, Research Report for SGEM (Smart Grids and Energy Markets) project

[19] P. Valtonen, J. Partanen and N. Belonogova, *The role and business potential of customer load control in an electricity retailer's short-term profit optimization*, NORDAC 2012, 10th Nordic Conference on Electricity Distribution System Management and Development, Espoo, Finland, 2012

[20] WWW-pages of Nordic power exchange Nord Pool Spot, 2012
http://www.nordpoolspot.com/TAS/Day-ahead-market-Elspot/
http://www.nordpoolspot.com/TAS/Intraday-market-Elbas/

[21] WWW-pages of The Finnish transmission system operator Fingrid, 2012
http://www.fingrid.fi/portal/in_english/services/balance_services/imbalance_settlement
http://www.fingrid.fi/portal/in_english/services/balance_services/balancing_power_market/

[22] P. Valtonen, S. Honkapuro and J. Partanen, *Impacts of Smart Grids on Electricity Retail Business*, CIRED, 21st International Conference on Electricity Distribution, Frankfurt, Germany, June 2011

[23] T. Kaipia, J. Partanen and P. Järventausta, Concept of Interactive Customer Gateway, Research Report for INCA project, Lappeenranta University of Technology, September 2010

[24] *Kotitalouksien sähkönkäyttö 2006 [Households' electricity usage in 2006]*, Research report, Adato, ISBN-978-952-9696-41-3, 2008 (In Finnish)