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Petri Valtonen

DISTRIBUTED ENERGY RESOURCES IN AN ELECTRICITY RETAILER'S SHORT-TERM PROFIT OPTIMIZATION

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Abstract

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Liberalization of electricity markets has resulted in a competed Nordic electricity market, in which electricity retailers play a key role as electricity suppliers, market intermediaries, and service providers. Although these roles may remain unchanged in the near future, the retailers' operation may change fundamentally as a result of the emerging smart grid environment. Especially the increasing amount of distributed energy resources (DER), and improving opportunities for their control, are reshaping the operating environment of the retailers. This requires that the retailers' operation models are developed to match the operating environment, in which the active use of DER plays a major role.

Electricity retailers have a clientele, and they operate actively in the electricity markets, which makes them a natural market party to offer new services for end-users aiming at an efficient and market-based use of DER. From the retailer's point of view, the active use of DER can provide means to adapt the operation to meet the challenges posed by the smart grid environment, and to pursue the ultimate objective of the retailer, which is to maximize the profit of operation.

This doctoral dissertation introduces a methodology for the comprehensive use of DER in an electricity retailer's short-term profit optimization that covers operation in a variety of marketplaces including day-ahead, intra-day, and reserve markets. The analysis results provide data of the key profit-making opportunities and the risks associated with different types of DER use. Therefore, the methodology may serve as an efficient tool for an experienced operator in the planning of the optimal market-based DER use.

The key contributions of this doctoral dissertation lie in the analysis and development of the model that allows the retailer to benefit from profit-making opportunities brought by the use of DER in different marketplaces, but also to manage the major risks involved in the active use of DER. In addition, the dissertation introduces an analysis of the economic potential of DER control actions in different marketplaces including the day-ahead Elspot market, balancing power market, and the hourly market of Frequency Containment Reserve for Disturbances (FCR-D).

Keywords: DER, economic potential, electricity markets, electricity retailer, load control, reserve market, risk management, profit optimization, short-term operation, short-term profit optimization

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Contents

Abbreviations

AMR	automatic meter reading
AMI	advanced metering infrastructure
ARMA	autoregressive moving average
EES	electrical energy storage
EET	East European Time
EPAD	electricity price area differential
CET	Central European Time
CG	control group
CPP	critical peak pricing
C-VaR	conditional value at risk
DR	demand response
DER	distributed energy resources
DG	distributed generation
DSM	demand side management
FCR	Frequency Containment Reserve
FCR-D	Frequency Containment Reserve for Disturbances
FCR-N	Frequency Containment Reserve for Normal Operation
FRR	Frequency Restoration Reserve
FRR-A	Automatic Frequency Restoration Reserve
FRR-M	Manual Frequency Restoration Reserve
GARCH	generalized autoregressive conditional heteroscedasticity
HEMS	Home Energy Management System
OMX	A Swedish-Finnish financial services company, formed in 2003 through a merger between OM AB and HEX plc; part of the NASDAQ OMX Group since February 2008.
OTC	over-the-counter
RAROC	risk adjusted return on capital
RTP	real time pricing
SARIMA	Seasonal Autoregressive Integrated Moving Average
TOU	time-of-use
MVA	megavolt amperes
MW	megawatt
MWh	megawatt hour

1 Introduction

The transition into the future smart grid environment is changing the operating environment and the market players' business. Traditionally, an electricity retailer's role has been that of a market intermediary that acquires electricity in the wholesale market and retails it to residential, commercial, and industrial consumers. Although this practice may remain unchanged, in the future smart grid environment, the retailers may play an increasingly important role as market players that use end-users' aggregated distributed energy resources (DER) actively in various marketplaces including day-ahead and intra-day energy markets and different reserve markets, or corresponding ancillary services. In particular, integration of intermittent generation increases the need for ancillary services and reserve power that the active use of DER can offer. Simultaneously, the active use of DER can provide new tools for the retailer's profit optimization.

In this doctoral dissertation, electricity retailer's profit optimization refers to the retailer operation that ultimately aims at the maximization of the profits of operation, but also involves many other aspects such as risk management. According to the operation horizon, the retailer's profit optimization can be divided into long-term strategic planning (operation) and short-term operation. At the time of long-term planning, the retailer aims at ensuring the viability of the retail business by hedging against the major risks and establishing retail sales contracts that produce sales income. At the time of short-term operation, the retailer operates actively in the wholesale markets by purchasing and selling energy in order to supply the energy consumed by its customers upon their demand, and to maximize the expected profit of operation. The doctoral dissertation focuses on the retailer's short-term operation with a special reference to the use of DER.

The particular features of electricity require the use of market and operation models designed specifically for the purpose. This makes also the electricity retail business unique and poses challenges to the retailer's profit optimization; business and operation models used in other businesses may be inapplicable to the electricity retail as such. Consequently, the models used for the electricity retailer's profit optimization have to be designed by taking into account the specific features of the operating and market environment. Electricity is characterized as a commodity that cannot be stored economically. In addition, it has to be delivered to the end-users over transmission and distribution grids. Moreover, electricity production has to match the consumption in the power system each moment to guarantee the reliable operation of the system. Although these fundamentals may mainly remain unchanged, they are yet challenged, at least to some extent, by the transition into the future smart grid environment.

In the future smart grid environment, an increasing proportion of electricity is produced by distributed generation (DG), which mainly consists of intermittent renewables such as wind and solar production. The evolution of electrical energy storage (EES) technologies provides more cost efficient solutions for the efficient use of energy and the management of power balance between production and consumption. Developments in the electricity infrastructure and the increasing penetration of automation and control systems introduce more real-time control and monitoring applications, which, again, promote the more efficient use of DER. These fundamental changes in the operating environment may result in both risks and opportunities. For instance, the increasing penetration of intermittent renewables poses challenges to the management of the power balance between consumption and production, and may result in fluctuations in electricity prices. On the other hand, energy storage applications and sophisticated monitoring, control, and automation systems allow more efficient management of power balance, and can thus even out price variations.

It is not known for certain how the operating and market environment will change as a result of the ongoing developments; nevertheless, it seems that the dynamics of the power system is changing. Therefore, the applied operation models, including the retailer’s profit optimization models, are developed according to the current operating and market conditions. This doctoral dissertation aims at developing knowledge and establishing a methodological framework that can be used to address the key issues associated with the use of DER in an electricity retailer’s short-term profit optimization in the future smart grid environment. This objective is approached by considering the main issues related to the increasing penetration of DER from the perspective of the retailer’s short-term operation. To this end, the Nordic electricity markets and the Finnish reserve markets are used as example cases.

1.1 Research objectives, questions, and hypothesis

The main objective of this doctoral dissertation is to develop methodology for the comprehensive use of DER as part of an electricity retailer’s short-term profit optimization. This objective is based on the hypothesis that the future smart grid environment provides a platform that can be used by the retailer for active monitoring and control of DER.

In the methodology development, various aspects of the retailer operation have to be considered. For instance, the impacts of long-term planning decisions on the short-term operation, requirements set by various marketplaces for the use of DER, issues related to the planning and modelling of DER control actions, and risks associated with different operation strategies have to be taken into account. In order to approach the most essential elements in the development work, the focus is on the aspects that are considered the key issues in the planning and modelling of the retailer’s short-term profit optimization. Especially the profit-making potential provided by DER control actions in the case marketplaces and opportunities to harvest this potential are studied. Similarly, the identification and management of the risks involved in the retailer’s short-term operation with a special reference to the use of DER are analysed in detail. By focusing on these aspects and by taking into account the specific features of the operating and market environment, the methodology can be developed by considering the profit-making opportunities provided by the use of DER in various marketplaces and risks related to the retailer operation and the use of DER.

The developed methodology and the proposed modelling approach provide tools and answers to the following main research questions:

- What kinds of impacts may the emerging future smart grid environment have on the retailer operation?
- What kind of methodology enables comprehensive modelling of the use of DER as an element of the retailer operation?
- How can the main risks associated with DER control actions and retailer operation be managed, simultaneously taking advantage of the most significant profit-making opportunities?
- What is the economic potential of market-based DER control actions taken by an electricity retailer in different marketplaces?

The developed methodology, modelling approach, and analyses aim at addressing the above key research questions.

The work focuses on the Nordic electricity markets and the Finnish reserve markets. However, the methodology and modelling approach can be applied, to a certain degree, also to other markets of the same type. Detailed determination of optimal bidding strategies or optimization constraints, price and consumption forecasting and modelling approaches, or an optimal operation plan in a given situation are beyond the scope of this work. An analysis of the costs caused by the use of DER is not in the focus of this work either.

1.2 Scientific contribution

The main contribution of this doctoral dissertation lies in the analysis and modelling of the risks and profit-making opportunities related to the use of DER as part of an electricity retailer's short-term profit optimization that covers operation in a variety of marketplaces including day-ahead, intra-day, and reserve markets. The scientific contributions of the work are:

- Comprehensive methodology for the electricity retailer's short-term profit optimization
- Method to model and analyse the use of DER and the related risks in the retailer's short-term operation
- Analysis of the economic potential of DER control actions in various marketplaces including day-ahead and reserve markets. The results demonstrate the high relative economic potential of reserve markets.
- Analysis of the risks and profit-making opportunities of the active use of DER, which shows that the profits increase significantly if the retailer is able to exploit at least the profit-making potential of a few highest-price hours of the year and to manage the involved risks.

By the above contributions, an electricity retailer, or other market-based operator such an aggregator, is able to analyse the effects of the DER use on the risks and profit-making potential of the operation, and can derive an advantageous short-term operation plan.

1.3 Outline of the work

Chapter 2 introduces fundamentals of the electricity retail business and describes the retailer operation and the market environment. The main elements of the electricity retail business, structure, and operation in marketplaces of the Nordic electricity market and the Finnish reserve markets, and the key aspects of the current and future operating environment are presented.

Chapter 3 describes the central aspects of the planning of the retail business. The retailer operation and the key elements of the retail business are introduced. At the end of the chapter, a literature review on the long- and short-term planning is provided. Based on the review, methodological approaches suitable for modelling the retailer operation in the smart grid environment are analysed.

Chapter 4 presents approaches to the risks and use of DER as an element of the retailer's short-term profit optimization. Various aspects related to the modelling of retailer operation, different risks, and DER control actions are discussed and suitable modelling approaches are derived.

Chapter 5 provides a comprehensive model for the retailer's short-term profit optimization. The methodology is built on findings made in the course of the research and implemented as a comprehensive modelling approach, which is formulated in a modular manner according to the main stages of the short-term operation.

Chapter 6 addresses the economic potential provided by DER in the retailer's short-term profit optimization. An analysis and calculation model are used to estimate the economic potential provided by DER control actions as part of the retailer operation in different marketplaces.

Chapter 7 concludes the work and provides suggestions for further research.

2 Operating and market environment

The electricity sector has evolved from vertically integrated monopolies, which covered the whole electricity chain from supply, generation, transmission, and distribution to retail. The performance of these regulated monopolies has varied greatly across countries, but typically, high operating costs and retail prices have resulted in pressures for changes everywhere. Therefore, new institutional arrangements have taken place around the world aiming to provide long-term benefits, especially through competition in electric power production and retail, thereby reducing electricity costs and retail prices. The deregulation took place in the Nordic electricity markets over the nineties by opening the competition between power-generating companies through vertical separation of distribution and power supply and retail, and inducing stepwise market integration. Power supply and retail were opened up to competition, whereas distribution remained a natural monopoly. A common Nordic power exchange, Nord Pool, developed gradually around the deregulated market of Norway when Sweden (in 1996), Finland (in 1998), and Denmark (in 2000) joined the market. Since then, the Nordic markets have evolved to meet the challenges of the today's electricity business (Joskow, 2008; Lundgren, 2012; Makkonen, 2015).

The competed electricity retail supply has provided the residential consumers with the opportunity to choose their supplier. This has been one of the major changes in the electricity sector as it has increased the consumers' choices, aimed at reducing barriers to entry, and lowered the prices. Electricity retailers that operate as service providers and market intermediaries by acquiring electricity in the competitive wholesale market and retailing it to the consumers are an essential part of the competed power markets. The retailer operation in the competed market inherently includes the roles of a service provider, a market operator, and a supplier. In addition, the retailers already have a certain clientele, and the operation is market based. Therefore, an electricity retailer can be considered a natural market party to provide new services for end-users aiming at an efficient and market-based use of DER. Moreover, from the retailer's point of view, this can offer new means to pursue the ultimate objective of the retailer, which, similarly as for any other market-based operator, is to maximize the profit of the operation (Boroumand and Zachmann, 2011; Defeuilley, 2009; Fleten and Pettersen, 2005; Hatami et al., 2009; Nazari and Foroud, 2013).

2.1 Fundamentals of the electricity retail business

This section provides an overview of the fundamentals of the electricity retail business, which arise from certain specific features of electricity and the applied operation and market models. These aspects set the main guidelines on the retailer operation and planning of the retail business. Therefore, knowledge of the fundamentals is required as a basis for the development of a comprehensive model for the retailer's short-term profit optimization. This section introduces the basics of the electricity retail business, whereas a more comprehensive description of the retail business and its planning is provided in Chapter 3.

Electricity as a commodity has certain features that call for operation and market models specifically designed for the purpose. The fact that electricity cannot be stored as economically as most commodities and the need to use the transmission grid to deliver mass-produced electrical energy to the end-users set the basic requirements for the models to be applied. From the perspective of the electricity retailer operation, the requirement to maintain continued power balance between electricity consumption/sales and purchases/production is one of the operating fundamentals. Another elementary operation constraint is the retailer's load obligation, which requires that the retailer provides its customers with electricity upon their demand. In addition to these fundamentals, electricity markets and the characteristics of the operating environment set a number of constraints on the retailer operation, as will be discussed later.

The planning horizon in the electricity retailer business can cover operations starting from years before the delivery all the way to the delivery and the following market clearing. In the Finnish electricity markets, the market clearing is accomplished through imbalance settlement, in which all deliveries of the market parties are settled. Figure 2.1 provides a flow chart-based illustration of an electricity retailer's basic operation in the Nordic electricity markets on a timeline. It is pointed out that the illustration does not include the retailer operation in the marketplaces of the Finnish reserve system, with the exclusion of the balancing power market. The reserve market operation will be examined in more detail later on in this work.

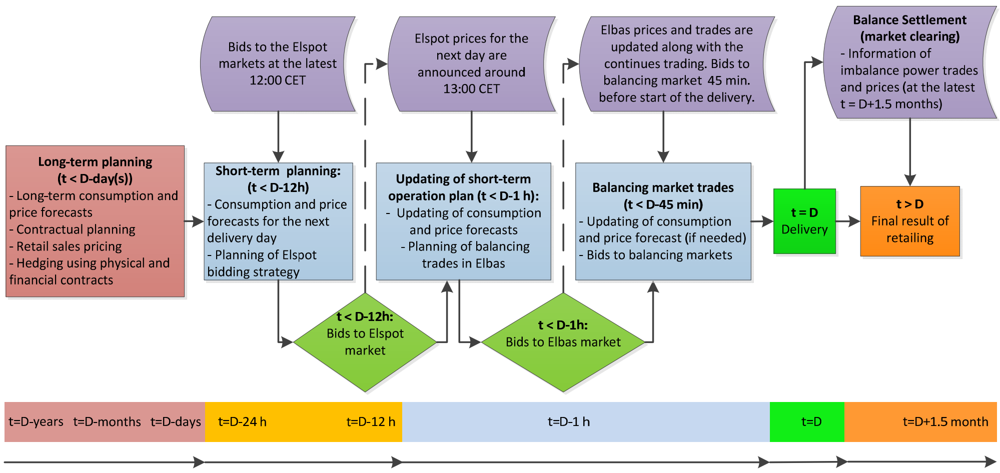

Figure 2.1. Electricity retailer operation in the Nordic electricity markets on a timeline.

Electricity retailer operation comprises a number of subsequent and partly overlapping operations. The time limits for the operations are presented in Figure 2.1 in relation to the moment of delivery, that is, the start of the first delivery hour of a day. The time limits set by the market for the retailer operation are expressed in Central European Time (CET).

The retailer's operations are represented on the timeline using expressions $t < Y$, $t > Y$ and $t=Y$, in which t denotes the time when an operation is accomplished and whether the time t takes place prior to, after, or at time Y, respectively. Time Y can also be expressed by denotations Y=D-X and Y=D+X, in which D denotes the moment of delivery, and X indicates how much before (-) or after (+) the delivery the operation takes place, respectively.

Strategic planning of the retail business, which is also referred to as long-term planning, takes place years to days before the delivery. Within this long-term planning horizon, electricity retailers aim at hedging against various risks mainly by physical and financial hedging contracts. Through them, the retailer can ensure a fixed purchase or sales price for the electricity well in advance. In addition, the retailer plans an appropriate retail sales pricing strategy within the long-term planning interval to ensure an adequate profit and/or risk margin for the operation.

The retailer's short-term operation starts from the planning of trades in the day-ahead Elspot market. The deadline for placing offers to the next-day delivery hours in Elspot is 12:00 CET. The Elspot trading is the main tool for the retailer's physical electricity procurements that have to be made to acquire the energy consumed by the customers and to establish a power balance between electricity purchases/production and sales/consumption. The retailer receives an announcement of the Elspot trades and prices around 13:00 CET. After this, the retailer can complete the required balancing trades in Elbas until one hour before the start of the delivery hour. The above-described sequential operation of the market can also provide arbitrage opportunities, which for instance a risk-taker retailer could aim to exploit. However, the main focus in the Elspot and Elbas trading is yet on the management of volume (imbalance) risk, which arises if the consumption does not match the electricity procurements.

Electricity retailers, or other operators that have production or consumption capacity that satisfies the specific requirements set by different reserve markets, can offer the capacity to the reserve use in order to obtain higher profits. For the sake of simplicity, Figure 2.1 takes into account only the balancing market trading opportunity, whereas other trading opportunities provided by other marketplaces of the reserve markets are considered later. In addition, here and later on it is assumed that the retailer under consideration does not operate as a producer. The bids to the balancing market can be placed until 45 minutes before the start of the delivery hour in question. After this, the retailer cannot place any offers to the markets. Therefore, the retailer cannot adjust its power balance by any means either, except for by controlling its consumption. However, the current operating environment generally does not provide feasible tools for this. According to the key hypothesis of this work, the future smart grid environment, instead, provides such tools. This enables the retailer to adjust its operation until the end of the delivery hour by controlling the end-users' consumption according to the profit maximization and risk management needs. Finally, after the end of the delivery, the imbalance settlement takes place. Here, all electricity deliveries between the market parties operating in the electricity market are determined and settled. After this, the final results of the retailing are known.

2.2 Retailer operation in the Nordic Electricity markets

The applied market model sets the main guidelines for the planning of the retailer operation. The characteristics of the current market environment define for example which instruments can be used for hedging, which marketplaces are used for trading of physical electricity, and what the time limits for different operations are. Therefore, knowledge of the market fundamentals is needed for the planning of the retailer operation and the market-based use of DER. Moreover, by in-depth knowledge of the market features, an electricity retailer may be able to derive superior trading and DER use plans in the future smart grid environment.

As introduced above, planning of the electricity retail business can be divided into long- and short-term planning according to the operation horizon. Figure 2.2 illustrates the long- and short-term planning of the electricity retail business in the Nordic electricity markets by placing the retailer's key operations in different marketplaces on a timeline.

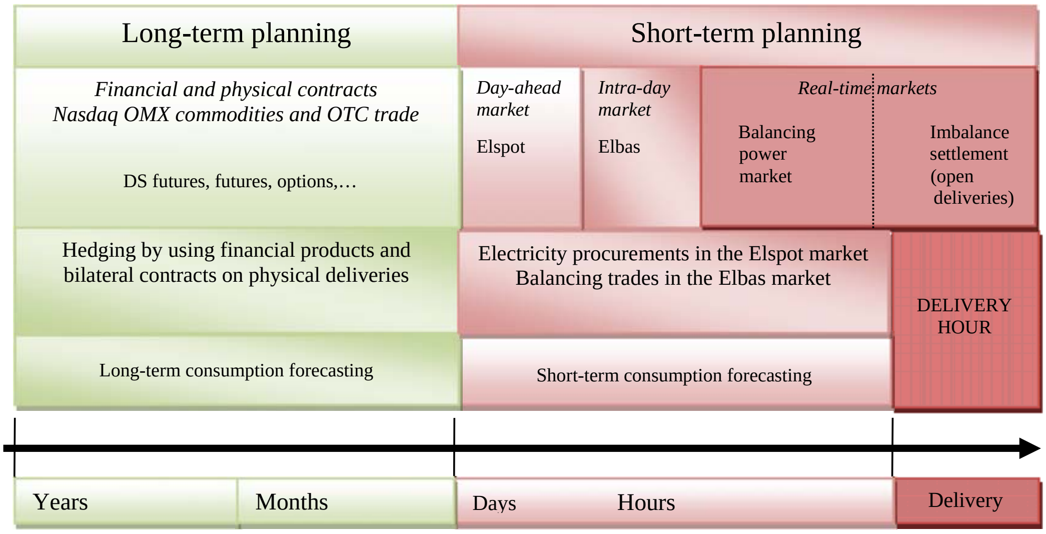

Figure 2.2. Long- and short-term planning of the retail business in the Nordic electricity markets. The key marketplaces and the retailer operations.

The key element of the long-term planning of the retail business, presented with a green background, is the risk management. By hedging against the market price risk, electricity retailers aim to ensure a favourable purchase or sales price for the electricity in advance. In the Nordic market, the main tools for hedging are the financial products of Nasdaq OMX. In addition, bilateral contracts on physical deliveries can be made through OTC (Over-The-Counter) trades. The financial contracts have a time horizon of up to six years, and they cover daily, weekly, monthly, quarterly, and annual contracts. The system price of Nord Pool Spot is used as the reference price for the financial contracts. The financial contracts do not lead to physical delivery, but are cash settled against the system price (Nord pool Spot, 2015a; Nasdaq OMX, 2015).

Short-term planning of the retailer's business, presented with a red background in Figure 2.2, comprises planning of trades in different short-term markets. The main objective in the short-term planning is to draw up a trading plan that allows the retailer to maximize the profits of the operation and ensures that the demanded energy can be procured in the markets. The central marketplaces in which the retailers operate on a daily basis include the day-ahead Elspot market and the intra-day Elbas market. In addition, after the delivery, the imbalance settlement takes place. Here, imbalance power trades are completed in order to settle all market parties' electricity deliveries.

In addition to the trading in the above-mentioned basic energy markets, electricity retailers can offer their controllable production and loads to the marketplaces of the Finnish reserve system maintained by the system operator Fingrid. The reserve markets provide additional profit-making opportunities for the use of controllable capacity, which can also include aggregated DER units. Although trading in these additional marketplaces of the reserve system is not typically at the core of the retailers' operation in the current operating environment, it may play an important role in the retailer's short-term operation in the future smart grid environment.

Next, the key marketplaces from the perspective of the retailer's daily-basis short-term operation and the use of DER are examined. First, the Nordic electricity markets operated by Nord Pool Spot are introduced. After that, the Finnish reserve system and the markets operated by the system operator Fingrid are described. Finally, the imbalance settlement is elaborated on.

2.2.1 Nordic electricity markets

Nord Pool Spot is the leading power market in Europe, offering both day-ahead and intraday markets. In 2013, about 88 % of the total Nordic electricity consumption was traded in Nord Pool Spot. The day-ahead market Elspot is the world's largest day-ahead market for trading power. Therefore, Elspot provides a liquid, safe, and transparent marketplace for trading in the Nordic region. The intra-day market Elbas is a balancing market that provides an opportunity for the market parties to adjust their physical positions close to the moment of delivery before the final balancing measures are completed by the system operators (Nord Pool Spot, 2015b; NordREG, 2014).

In Elspot, hourly power contracts are traded for a physical delivery of the next day. The market participants can place their orders up to twelve days ahead while the gate closure for the orders for the next day delivery is 12:00 CET. After all market parties have submitted their offers, Nord Pool Spot calculates the system price and area prices and announces them around 13:00 CET. All physical trades are settled in Elspot based on area prices, whereas the system price is used as a general reference price, for instance in the settlement of financial contracts (Nord Pool Spot, 2015b).

The balance between supply and demand is mainly secured through Elspot trades, but because the period between closing of Elspot 12:00 CET and the next-day delivery is many hours, needs for balancing trades may arise. Elbas provides an opportunity for electricity retailers and other market parties to adjust their power balance close to the moment of delivery. Elbas is a continuous market, where trading takes place every day around the clock until one hour before delivery. At 14:00 CET, the hour contracts for the next day are opened and the trading starts. Transactions between the market parties are matched automatically as soon as concurring based on a first-come, first-served principle, where the lowest sell price and the highest buy price are at the first place (Nord Pool Spot, 2015b; 2015c).

Elbas provides an opportunity for the market players to procure electricity at a lower price than in the balancing market (through imbalance power trades/imbalance settlement). Therefore, the Elbas market can be used as an alternative to the balancing market trades for all or some of the imbalance that a market player may have after the day-ahead trades. Because the price is known prior to the delivery hour, balancing trades in the Elbas markets can be used to reduce the retailer’s risk related to imbalance.

2.2.2 Finnish reserve system and markets operated by Fingrid

The spot market facilitates balancing of the estimated production and consumption, but real-time imbalances may still take place. Physical balancing of supply and demand is ensured by a joint Nordic reserve system (Finland, Sweden, Norway, and Denmark). The obligations for maintaining reserves are divided between the system operators, and each of them procures its share of reserves as it considers best. System operators acquire reserve capacity for instance through long-term contracts and hourly markets. In this work, the Finnish reserve system (mechanism) and the markets operated by Fingrid are under consideration. The reserve products used in Finland are presented in Figure 2.3 (Boomsma et al., 2013; Fingrid, 2015a; 2015b).

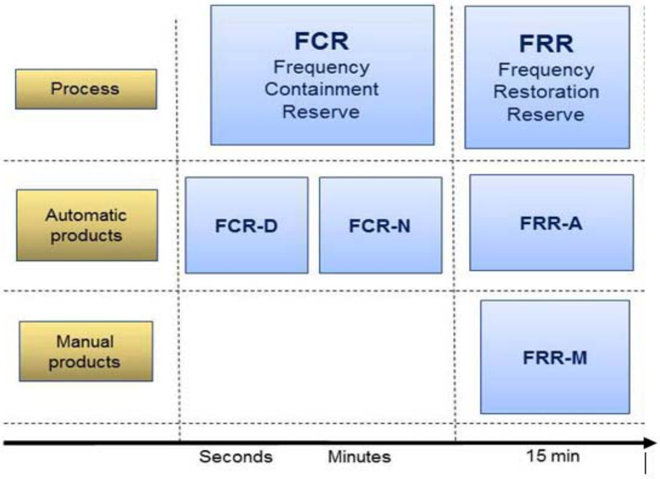

Figure 2.3. Reserve products used in Finland (Fingrid, 2015c).

Fingrid acquires different reserve products that react to changes in consumption and production at different levels of time. The reserves used in Finland can be divided into two groups based on the purpose of use:

1. Frequency containment reserves are used for the constant control of frequency.
2. Frequency restoration reserves are used to restore the frequency to its normal range and to release activated frequency containment reserves back into use.

The balance between consumption and production at any given moment is indicated by the frequency of the electricity grid. The frequency falls below the nominal value of 50.0 Hz when consumption is greater than production. Correspondingly, the frequency exceeds the 50.0 Hz value when production is greater than consumption. Frequency Containment Reserve for Normal operation (FCR-N) and Frequency Containment Reserve for Disturbances (FCR-D) are active power reserves, which are automatically activated by changes in frequency. The purpose of the FCR-N is to maintain the frequency within the normal range of 49.9–50.1 Hz, and the aim of the FCR-D is to replace the production deficit in the case of unexpected disconnection of generation or an interconnector (Fingrid, 2015d).

The Automatic Frequency Restoration Reserve (FRR-A) is an automatically activated reserve, which is used to restore the frequency to the nominal value of 50 Hz. The activation is based on a power change signal calculated and sent by Fingrid. The Manual Frequency Restoration Reserve (FRR-M) comprises market-based regulating bids in the balancing power market, which is also referred to as regulating power market, and capacity that the system operator reserves for disturbances. Activation is done manually based on Fingrid’s orders (Fingrid, 2015e).

Fingrid procures the above-described reserves through long-term contracts, yearly markets, and hourly markets, and therefore, participation in the reserve markets always requires entering into a specific agreement with Fingrid. The terms of the agreement set the requirements on the capacity offered in a particular reserve use, pricing mechanisms, contract parties' obligations, and other key issues related to the trading and the use of capacity. Long-term and yearly market agreements obligate the contract party to provide the particular product, in other words, the contracted capacity, around the year (with some exceptions), and the pricing of the reserve capacity is fixed over this period. Because this work focuses on the retailer's short-term operation, trading of capacity in the reserve markets through long-term contracts or yearly markets is not considered in more detail. Instead, the focus is on the use of DER through hourly reserve markets.

Hourly market agreements, similarly as long-term and yearly market agreements, set requirements on the capacity offered to the reserve use, market parties' obligations, and other related issues. However, hourly market agreements, unlike long-term agreements, do not obligate the contract party to offer the control capacity for the reserve use around the year. Instead, the contract party can offer the capacity to the hourly reserve markets for any specific hours as it considers best (as long as the contract terms are followed). Therefore, hourly reserve markets provide potential marketplaces for the use of different types of DER capacity that may be available for the use only at specific times.

Aggregated DER capacity can be offered similarly to the hourly reserve markets as in the basic energy markets, that is, the Elspot and Elbas markets. In addition, in the future smart grid environment, the retailer can use DER in the balance management to adjust its power balance by controlling its consumption instead or in addition to balancing trades. Thus, the retailer's balance management can be seen as an additional marketplace for the use of DER. The main marketplaces of the Nordic electricity markets and the Finnish reserve system, including the retailer's balancing management, are summarized in Table 2.1 from the perspective of the use of DER as part of the retailer's short-term operation. The table also presents the key requirements set on the capacity offered in each marketplace.

Table 2.1 Marketplaces for the use of DER in the retailer's short-term operation.

Marketplace	Contract type	Minimum size	Activation time	Activation frequency	Pricing
Frequency-controlled normal operation reserve (FCR-N)	Hourly market	0.1 MW	In 3 minutes when frequency changes $\pm$ 0.1 Hz.	Constantly	Hourly market price (power capacity) + energy price
Frequency-controlled disturbance reserve (FCR-D)	Hourly market	1 MW	Power plant machinery: 50% in 5 seconds when frequency under 49.9 Hz, 100% in 30 seconds when frequency under 49.5 Hz Relay-connected load: disconnection in 30 seconds when frequency under 49.7 Hz and in 5 seconds when frequency under 49.5 Hz	Several times per day	Hourly market price (power capacity)
Automatic Frequency Restoration Reserve (FRR-A)	Hourly market	5 MW	Must begin within 30 seconds of the signal reception and fully activated in 2 minutes	Several times per day	Hourly market price (power capacity) + energy price
Balancing power market (FRR-M)	Hourly market	10 MW	15 minutes	According to the bids, several times per day	Hourly market price (energy)
Elspot	Hourly market	0.1 MW	12 h	-	Hourly market price
Elbas	Hourly market	0.1 MW	1 h	-	Hourly market price
Retailer's balance management	Balance service agreement	-	In some minutes	-	Hourly market price

Table 2.1 shows that there are a number of hourly markets in which aggregated DER capacity can be used. Each of these marketplaces sets requirements of its own for the capacity use, for instance with respect to the minimum size and activation time. In general, reserve markets set higher requirements on the control capacity than other

marketplaces. The pricing of the capacity also varies between the marketplaces. In the reserve markets, except for the balancing power market, the pricing is mainly based on the reserved power capacity. In addition, energy fees are generally paid of the use of the capacity. The market party is compensated for the balance deviation resulting from the reserve use by energy fees. For instance the Application Instruction for the Maintenance of Frequency Controlled Reserves as of 1 January 2015 states as follows: “The balance error caused by the frequency controlled normal operation reserve is calculated hourly and removed by means of a transaction from the balance of Reserve Holder’s balance provider in conjunction with the nation-wide balance settlement. Balance error caused by production is taken into account in the production balance, and, correspondingly, a balance error caused by a load is taken into account in the consumption balance. The basis of compensation is the hourly regulating price” (FCR, 2015).

Finally, from the perspective of the market-based use of DER, the reserved power capacity plays a significant role in the reserve markets. In the hourly reserve markets, with the exclusion of the balancing power market, pricing is mainly based on the reserved power capacity, although also energy fees are included in the pricing models. The operator of the control capacity is usually compensated for the imbalance resulting from the reserve use during the delivery hour in question in the hourly reserve markets. The hourly market prices are determined based on the market parties’ bids separately for each hour. The balancing power market differs from other marketplaces under the reserve system in that the market parties are paid mainly according to the traded energy, although the minimum capacity requirement is still applied. The balancing power market can also be seen as a Nordic market in that Fingrid maintains the market together with the other Nordic transmission system operators. However, the trading arrangements still take place at the national level.

2.2.3 Nordic balance service model and imbalance settlement

The balance service model has been revised and uniform basic principles have been introduced in the Nordic countries. The model is based on the introduction of two types of balance: production and consumption balance. This model of two balances divides generation into one balance and consumption, purchases, and sales into another. In addition, the pricing models of these two balances are different. In the two-price system, the balance deviation of the production balance is used, while in the one-price system, the balance deviation of the consumption balance is applied. Figure 2.4 describes the model of two balances (Fingrid, 2015f).

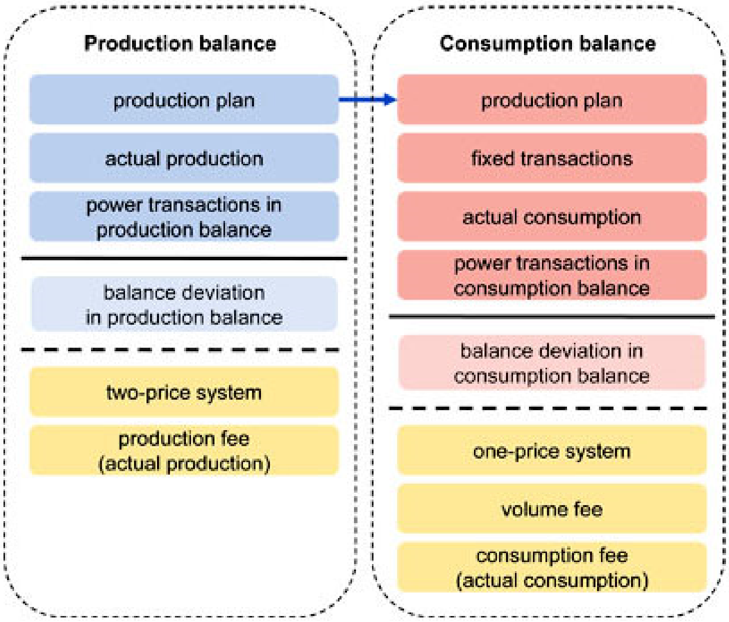

Figure 2.4. Model of two balances (Fingrid 2011).

The production balance is composed of a balance responsible party's total production plan and actual production covering the power plant generators with a nominal power of 1 MVA or above. Generators under 1 MVA are considered part of the consumption balance and are handled in the consumption balance so that they reduce the total consumption. The use of larger production as part of the retailer operation is not in the focus of this work, and therefore, only the key aspects are addressed related to the management of the retailer's consumption balance, in which also small-scale DER under 1 MWA nominal power is included (Fingrid, 2015f).

The consumption balance comprises a balance responsible party's total production plan, fixed transactions, and actual consumption. If there is a difference between the actual consumption and electricity purchases (fixed transactions, production plan), balance deviation in the consumption balance occurs. If the actual consumption of the balance responsible party is higher than estimated, a deficit in the consumption balance occurs, and if the reverse is true, there is a surplus in the consumption balance. In the case of a deficit, the balance responsible party purchases imbalance power from Fingrid in order to cover the deficit, whereas in the case of a surplus, the balance responsible party sells imbalance power to Fingrid in order to balance the surplus. In the consumption balance, a one-price system is adopted to the pricing of the imbalance power. This means that the purchase and sales prices of the imbalance power are the same. In addition, consumption imbalance power trades are subject to a volume and consumption fee (Fingrid, 2015g).

The last transactions in the physical power markets are completed by the system operator during the actual hour of operation to maintain the power balance in each country. As described in the previous section, the system operator maintains the reserve system that comprises frequency-controlled reserves and manual regulations to take continuous care of the power balance. If it is not possible to keep the frequency within the permitted limits by using frequency-controlled reserves, manual up-regulation or down-regulation is carried out in the balancing power market. The balancing power market in Finland is maintained by Fingrid, and it is part of the Nordic balancing power market. A Nordic balancing bid list is drawn up of all balancing bids by placing the bids in a price order. To maintain the frequency within acceptable limits, the balancing bids are used in the price order as well as possible. The lowest up-regulating bid (upper balancing power bid) is used first, and correspondingly, the highest down-regulating bid (lower balancing power bid) is used first. Figure 2.5 illustrates the use of balancing bids in the Nordic balancing power markets (Fingrid, 2015b).

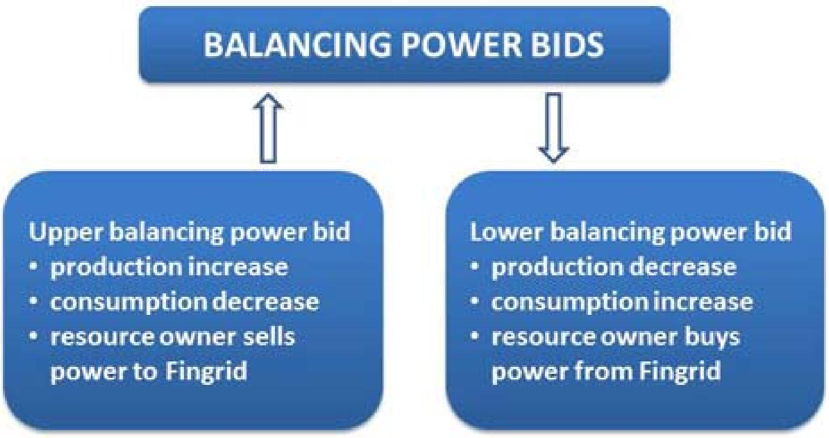

Figure 2.5. Use of balancing bids in the Nordic balancing power markets (Fingrid, 2015b).

Based on the regulations of the Nordic balancing power markets and the bids, the prices of balancing power are determined by both up-regulating and down-regulating power. The prices of balancing power, again, serve as the basis of the pricing of imbalance power. Fingrid's definition for the imbalance power is as follows: "Electric energy used for covering the balance deviation arising for a party during a specific hour. The open supplier of the party delivers this energy to the party in question through an open delivery. The volume of imbalance power is determined on the basis of the nation-wide imbalance settlement" (Fingrid, 2015h).

Imbalance settlement is used to determine the deliveries of electricity between the parties operating in the electricity market, and it is based on a hierarchic imbalance settlement model and chains of open deliveries. The basic reason for the imbalance settlement is that although each market party operating in the electricity markets must take continuous care of its power balance, in practice, the party is not able to accomplish this on its own. Therefore, it must have an open supplier that balances the power balance of the party. By signing the balance service agreement, the market party obtains an open electricity delivery and also the services related to the imbalance settlement and an opportunity to participate in the balancing power market. The market party that has signed the agreement is referred to as the balance responsible party. Figure 2.6 illustrates the chain of open deliveries (Fingrid, 2015i).

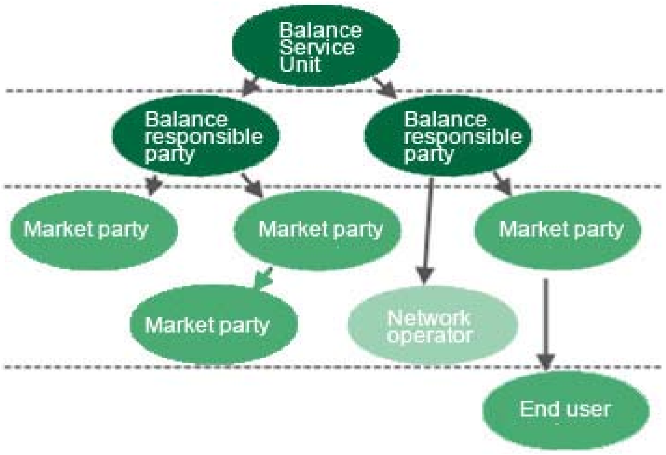

Figure 2.6. Chain of open deliveries (Fingrid, 2015i).

The calculations of open deliveries under imbalance settlement are based on hourly energies, which are obtained from hourly energy measurements, load profiles, production plans, and fixed deliveries. As a result of the imbalance settlement, the power balance of each market is obtained. In addition, the imbalance settlement connects the market parties and balancing power markets.

2.3 Role of the operating environment

Besides the market environment, the current operating environment sets guidelines for the retailer operation. The operating environment defines, for example, what kinds of data and measurements are available as inputs for planning of the operation, and what kinds of tools can be used for the profit optimization. For instance, in the current operating environment, the retailer does not have tools for the balance management after the trading in the Elbas market has terminated. However, in the future smart grid environment, the application of controllable DER allows the retailer to manage its power balance all the way to the end of the delivery hour by controlling end-user loads based on recent measurements and forecasts.

The developments in the operating environment can fundamentally change the nature of the retail business. The transition into the future smart grid environment, in which the retailer can use real-time measurements, advanced optimization and control applications, and other resources available, can provide the retailer with a number of new tools that enhance the short-term profit optimization. This section introduces the current operating environment and describes the future smart grid environment as it is perceived in this doctoral dissertation.

2.3.1 Current operating environment

One of the main challenges in the retailer's short-term profit optimization is the uncertainty associated with the future electricity consumption and price. Although electricity consumption can be forecasted with a considerably high accuracy in the short run, there are usually some forecasting errors that make it difficult to plan electricity procurements to match the actual consumption. In addition, the future prices involve even higher uncertainties than the electricity demand. Consequently, the retailer is exposed to high risks, which call for an appropriate risk management. Although a retailer can hedge against the risks in the long term, the unforeseen fluctuations in the future consumption and prices always pose some risks to the retailer. Consequently, the retailer's success in the profit optimization depends largely on how the retailer is able to forecast the future consumption and prices. In addition, the characteristics of the current operating environment also have to be taken account of because they have an effect on typical variations in consumption and prices, and the retailer's ability to monitor and control its consumption according to the profit maximization needs.

In order to draw up a feasible short-term operation plan, the retailer needs an accurate forecast of the future consumption. Price forecasts can also provide very useful input data for the planning of operation, but the high uncertainty related to the price forecasts can make their efficient use challenging. The performance of the forecasting applications depends not only on the forecasting model itself, but also on other issues such as the input data that the model uses, and/or is used to tune the model. Basically, this means that the more accurate and real-time data there are available for the forecasting, the better is the performance of the forecasting model (Mutanen et al., 2011; Voronin, 2013).

Traditionally, the main function of energy meters has been to gather electricity consumption data for invoicing needs. However, the implementation of AMR (Automatic Meter Reading) meters and AMI (Advanced Metering Infrastructure) has brought new functionalities and made the acquisition of customer hourly consumption data easier for different purposes. For instance, by the data provided by the AMR infrastructure, it is possible to develop load profiling, consumption forecasting, and other applications that can further assist the retailer to establish an appropriate hedging and compile an advantageous short-term operation plan (Valtonen et al. 2010a; 2010b).

In Finland, large-scale implementation of AMR meters was put into action by the Finnish Government Decree *Valtioneuvoston asetus sähköntoimitusten selvityksestä ja mittauksesta* VNa 66/2009 (Government Decree on Determination of Electricity Supply and Metering), which requires that the DSOs install remote readable meters for at least 80 % of their customers. At the moment, a majority of the DSOs have installed smart meters to all their customers. Therefore, the penetration level of AMR meters is close to 100 %. The decree also provides that the meter has to register hourly electricity consumption, and shall be capable of receiving and executing or forwarding load control commands sent through the data transmission network. Also other reforms of legislation have affected the current operating environment over the recent years. For instance the Finnish Act *Laki energiamarkkinoilla toimivien yritysten energiatehokkuuspalveluista 1211/2009* (The Act on Energy Efficiency Services for Companies Operating in the Energy Market) obligates the local DSOs to provide the data needed for reporting the customers' energy consumption to the retailer without any payments. The act also provides that electricity retailers submit a consumption report to their customers at least once in a year (Laki energiamarkkinoilla toimivien yritysten energiatehokkuuspalveluista 1211/2009; VNa 66/2009).

As described above, legislative measures have considerably shaped the operating environment of the electricity retailers, particularly as a result of the large-scale implementation of AMR and enhanced availability and mobility of hourly energy consumption data. The ARM infrastructure has brought along two-way communications and new functionalities at customer interfaces. In principle, the existing AMR infrastructure should enable execution of the basic load control actions on a wide scale, and thus provide a basic platform for the demand side management (DSM) and large-scale demand response (DR). For example according to (Albadi and El-Saadany, 2007a), the DSM refers to the planning, implementation, and monitoring of the utility activities designed to influence the customer's electricity use in ways that will produce desired changes in the utility's load shape, that is, changes in the time pattern and magnitude of the utility's load. The demand response, again, is defined for instance by the Federal Energy Regulatory Commission (FERC, 2012) as "Changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."

Despite the recent development in the operating environment, the retailers still have rather limited options to exploit the potential offered by the present AMR infrastructure. For instance, unclear responsibilities of the market parties, a lack of common operation models, and missing standards for the data system interfaces have been recognized as significant obstacles. In addition, the AMR infrastructure has limitations of its own. Especially, occasional long data transfer delays, heterogeneity of systems and solutions including smart meters and data systems, and limitedness of the first-generation AMR meters for the implementation of different types of control and automation applications cause barriers to the implementation of extensive DSM and DR. Moreover, the concern of the implementation costs and the low economic potential have also been recognized as key issues that have hindered the promotion of demand response actions.

To sum up, the existing AMR infrastructure provides a basic platform for various DSM and DR actions, which basically means the optimized use of DER. However, there are also a number of obstacles that have hampered the efficient use of the present AMR infrastructure, and slowed down the efficient use of DER. Therefore, the tools available for the retailers' profit optimization are rather limited in the current operating conditions. Hence, a typical approach for the retailer's short-term profit optimization is to hedge against major risks and to aim at ensuring adequate sales incomes by acquiring retail customers in the long run.

The main focus in the short-term profit optimization is typically on the minimization of the electricity procurement costs. A common approach to the cost minimization is that the retailer first aims at procuring a majority of the energy demanded by the customers in the Elspot market in order to minimize power imbalance after the Elspot trades. However, as a result of the demand uncertainty, some imbalance typically occurs. Again, in order to avoid high imbalance power costs, the retailer next aims to minimize the current power imbalances by making balancing trades in the Elbas market. Finally, imbalance power trades are completed through a chain of open deliveries to establish a power balance. In addition, the retailers that have controllable loads and production may offer them in the Finnish reserve markets in order to obtain additional incomes. However, this is not at the core of most retailers' current operation. Figure 2.7 illustrates the main components of the retailer's short-term profit optimization in the current operating environment.

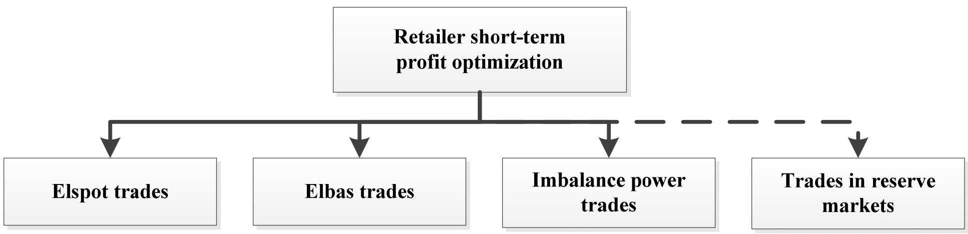

Figure 2.7. Main components of the retailer's short-term profit optimization in the current operating environment.

2.3.2 Smart grid environment

According to the key hypothesis of this doctoral dissertation, the future smart grid environment provides a platform that can be used by the electricity retailers for monitoring and control of DER. This includes almost real-time execution and verification of DER control actions, sophisticated forecasting applications that produce accurate forecasts as input data for the planning of control actions, and other elements that are needed for the efficient use of DER in the retailer's short-term profit optimization.

The future smart grid environment, and especially, the application of controllable DER, provide additional tools for the retailer's short-term profit optimization, whereas the retailer's tools in the current operating environment are rather limited, as discussed above. The ability to use DER actively within the short-term operation allows the retailer to operate more flexibly, because in addition to the traditional means (trading in the short-term markets), the retailer can also manage the balance between electricity consumption and procurements by using DER. The retailer uses its customers' DER units according to its profit optimization needs, but within the limits set by the customers. In practice, the specific use of DER can be agreed with the customers for instance by making contracts that define the constraints for the control action and compensations paid to the customers.

As introduced above, the AMR infrastructure provides a basic platform for the active use of DER in the retailer's short-term profit optimization, but there are still a number of obstacles that hinder its efficient use. Despite this, it can be seen as a first major step from traditional passive distribution networks to active smart grids. A central element of the future smart grid is the interactive customer gateway, which enables a flexible use of customers' loads, energy storages, and distributed generation. Figure 2.8 presents the concept of an interactive customer gateway.

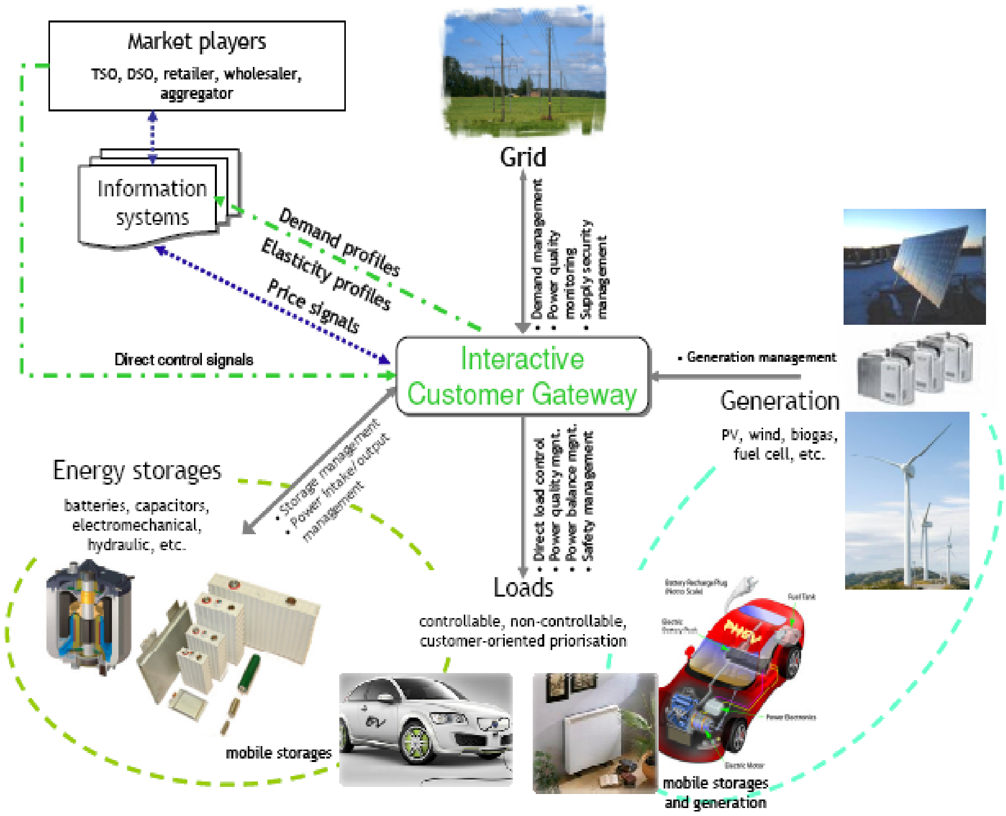

Figure 2.8. Interactive customer gateway (Kaipia et al., 2011).

A central element of the interactive customer gateway is a two-way data transfer connection, which enables real-time data transfer between different market parties and transmission of control signals. The customer interface connects the customers' DER units, which include different types of loads, energy storages, and distributed generation, to the power grid allowing power transmission in both directions; from the grid to the customer and from the customer to the grid. The interface can be used to control the DER units locally, for instance based on frequency. Similarly, fast and bi-directional communication between market parties and the customer gateway facilitates centralized control actions, which are implemented based on the control signals sent by the market players (Kaipia et al., 2011).

Although it is not known for certain which form the future smart grid will take, a general way of thinking mainly follows the above-introduced concept of an interactive customer gateway. For instance, the European Technology Platform defines the smart grid as follows: "A smart grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both in order to efficiently deliver sustainable, economic and secure electricity supplies." Studies in the field generally state that the smart grid must ensure safe, secure, uninterrupted, and sustainable electricity supplies, take advantage of new technologies, and enable large-scale integration of DG into the power system. In addition, it must promote efficient delivery and use of power through dynamic pricing and active DSM put into action by the market players. It is also generally agreed that the smart grid comprises two-way data transfer and power flows, and integrates individual technologies such as DGs, demand-side management, electric cars, and other energy storage units to the grid, thereby enabling optimized control of the DER units (Brown and Zhou, 2013; European Commission, 2006; Luthra et al., 2015; Wang et al., 2014).

The smart grid environment can obviously offer solutions to many issues, but it may also raise new ones. It is almost universally agreed that the most significant challenges related to the emerging smart grid environment arise from the large-scale integration of intermittent renewables. Similarly as the integration of renewables, the large-scale control of DER involves problems related to uncertainties in electricity production/consumption, which pose further challenges to the power balance management. The higher fluctuations in production and consumption also increase the need for balancing power and can be reflected in electricity prices as increasing volatility. Consequently, despite the various potential benefits, the introduction of smart grids may also pose significant risks (European Commission, 2006; Aghaei and Alizadeh, 2012; Samadi et al., 2013; Wang et al.; 2014).

From the perspective of the retailer operation, the active use of DER in the short-term profit optimization brings new dimensions to the retailer's profit optimization compared with the current situation. The use of DER improves the retailer's ability to react fast to changes in the operating or market conditions, provides an additional tool for the risk management, and opens new profit-making opportunities in various marketplaces. The bidding of aggregated DER capacity to the reserve markets is one of the most potential profit-making opportunities. In addition, the use of DER along with the trading opportunities provided by other marketplaces can enable the retailer to take advantage of the market price variations, or at least minimize the risks associated with them. Furthermore, for instance the option to adjust the customers' consumption by DER control actions close to the delivery based on the recent consumption forecasts can help the retailer to efficiently manage its power balance, even if balancing is no longer possible in the Elbas market.

The smart grid environment can also generate new risks to the retail business. First, large-scale integration of intermittent renewables is expected to increase price variations, which usually mean higher risks for the retailers, but on the other hand, can provide profit-making opportunities. An increasing proportion of DG means that the customers also produce energy, which can reduce the retailer's sales volumes and reshape the typical load profiles. From the perspective of short-term profit optimization, this means that planning of electricity procurements and management of the retailer's power balance become more complicated. Similarly, DER control actions affect the customers' load profiles. The estimation and consideration of these impacts are essential in the planning of the retailer's short-term operation. Taking advantage of the profit-making potential provided by the DER control requires that the control actions are planned in parallel with the retailer's other operations. If the impacts of the planned DER control actions on the retailer's load profile are not considered in detail, the DER control actions can result in unexpected power imbalances, and thus expose the retailer to high risks.

To sum up, the efficient use of DER within the retailer's short-term profit optimization requires a comprehensive approach that simultaneously aims at maximizing the profits from the use of DER, takes into account the risks associated with DER control actions, and considers the interactions between the DER control and other operations of the retailer. In addition, the smart grid environment may bring fundamental changes to the retailer's operation, which must be taken into account. The increasing amount of DG, consisting mainly of intermittent renewables, may result in unexpected variations in the customers' consumption and electricity prices. This poses challenges to the planning of electricity procurements and may increase the retailer's market price risks exposure.

The most fundamental changes to the retailer operation will most likely include the active use of DER. In general, an ability to control the end-users' DER units allows the retailer to operate more flexibly, that is, to adjust the operation based on the changing operating and market conditions. Aggregated DER capacity can be used in various marketplaces; for instance, instead of making purchases of electricity at the time of an occasional price spike, the retailer can implement DER control actions that reduce the consumption. The aggregated DER capacity can also be offered to the reserve markets, which can provide a higher economic potential than the spot markets. Consequently, DER control actions offer various profit-making opportunities, but also involve considerable risks. Therefore, comprehensive planning of short-term profit optimization, in which both the options to use DER and the trading opportunities provided by different marketplaces are considered simultaneously, is highly important. Figure 2.9 illustrates the main components of the retailer's short-term profit optimization and the role of the active use of DER in the smart grid environment.

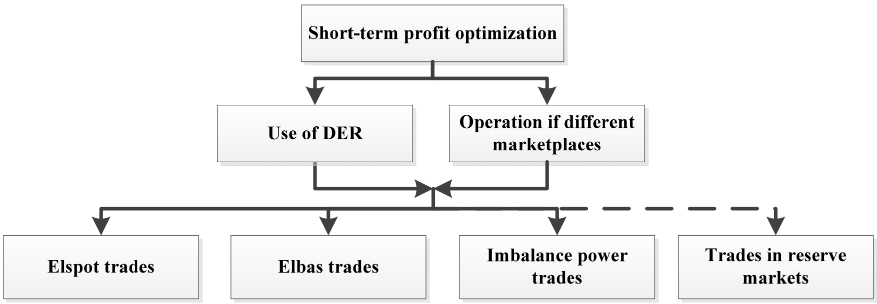

Figure 2.9. Main components of the retailer's short-term profit optimization in the smart grid environment.

3 Planning of the electricity retail business

The electricity business is characterized by certain distinctive features such as the requirement to maintain a continuous balance between electricity demand and supply, distribution of electricity through transmission and distribution networks, and the demand for high security of supply. These features necessitate the application of operational, market, and business models that are designed specifically for this kind of an operating environment. For the above reasons, many models used in other fields of businesses cannot be directly applied to the electricity retail business. In addition, the operation of electricity market parties is constrained by specific requirements set by the operation of the power system and electricity markets.

In the field of electricity retail business there are only a few studies on the active application of DER to the electricity retailer’s short-term profit optimization, or any comprehensive models available, for that matter. This study aims to bridge this research gap by introducing a new model for an electricity retailer’s short-term profit optimization in a future smart grid environment. The proposed profit optimization model incorporates the distinctive features of the operating and market environment, elaborates on the interactions between the long- and short-term operations, and provides a practical tool for the evaluation of an advantageous short-term profit optimization strategy based on the estimated market movements and operational situations. The development of the proposed model requires a detailed analysis of the constraints and profit-making opportunities provided by different marketplaces, consideration of various associated risk and operational aspects, and selection of a suitable methodological approach. To this end, the retailer’s profit maximization problem will be introduced and a short literature review of the topic will be given in this chapter. Moreover, the novelty of the research will also be validated through a literature review.

3.1 Retailer operation in the smart grid environment

An electricity retailer’s main objective, namely the maximization of profits of the retail business, can be expressed in a simplified form in a time interval $t = 0 \ldots T$ as

$$\text{Max} \int_0^T Profits(t)dt = \text{Max} \int_0^T (Incomes(t) - Costs(t))dt \tag{3.1}$$

In brief, the electricity retailer’s profit maximization problem consists of two main sub-problems; maximization of income and minimization of operational costs. In addition, a successful accomplishment of these tasks requires an appropriate risk management approach. A more detailed examination of the problem shows that the retailer’s profit optimization is a complex and multistage task that includes a long planning horizon, up to many years. Because of the long planning horizon, the partially stochastic nature of electricity price and consumption, and other related factors, the retailers have to make decisions on their future operation under considerable uncertainty. Consequently, careful planning of an appropriate profit optimization strategy, which considers various risks and different profit-making opportunities, is a prerequisite for a profitable retail business.

Although the retailer's profit optimization is a complex problem even in the current operating environment, it becomes even more complicated in the future smart grid environment, where the optimal use of controllable DER is also included in the problem. Figure 3.1 provides a flow chart of the retailer's operation in the case market environment and in the future smart grid environment on a timeline.

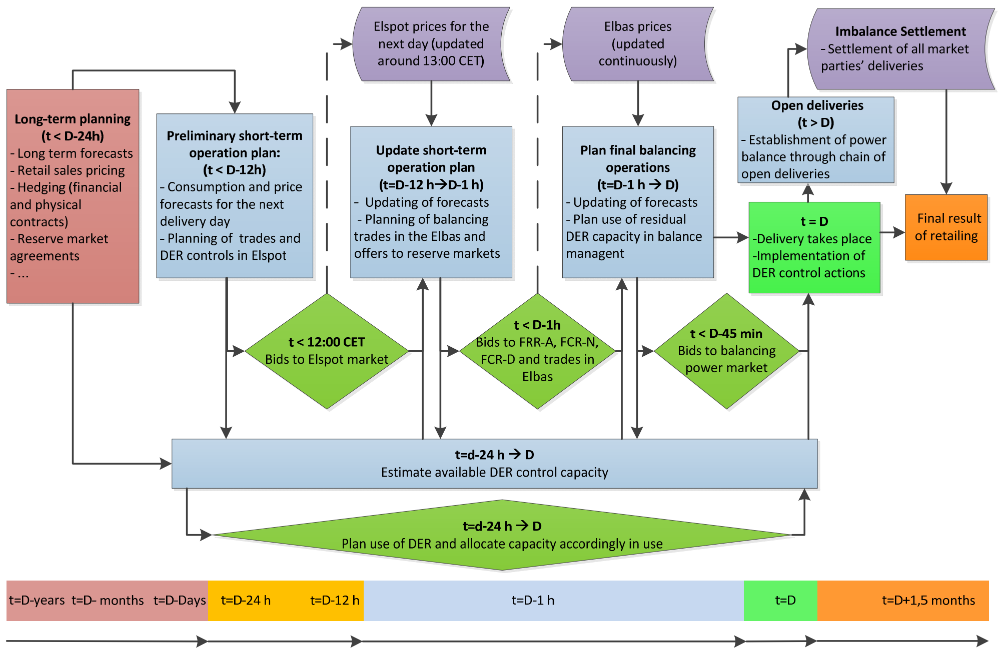

Figure 3.1. Electricity retailer's operation in the smart grid environment.

Figure 3.1 is based on Figure 2.1, which demonstrates the basic retailer operation in the markets of the current operating environment. Figure 3.1 is supplemented with elements involved in the use of controllable DER and trading reserve markets. These elements provide opportunities to enhance the profitability of the retail business in the future smart grid environment, but are not at the core of retailers' basic operation in the current operating environment.

The timeline of the retailer operation is presented at the bottom of Figure 3.1. The time periods and instants when different events take place are denoted by t and presented either in the form of time-of-day in CET (Central European Time) or with respect to the time of delivery, denoted by D, in a similar manner as in Figure 2.1. For instance, t = D - X h → D + Y h means that the event takes place within the time span that starts X hours prior to the delivery and ends Y hours after the delivery.

As Figure 3.1 illustrates, the electricity retailer's profit optimization in the smart grid environment is a dynamic process that consists of multiple sequential and partly simultaneous tasks. The long-term planning of the retail business covers establishment of an appropriate hedging and retail sales pricing strategy based on the long-term electricity price and consumption forecasts. In the short run, trading in the physical power markets is a central element of the retailer operation. Based on the short-term electricity price and consumption forecasts, and by considering the preceding decisions, the retailer trades energy in the day-ahead Elspot market and the intra-day Elbas market, and finally, through the chain of open deliveries in the imbalance settlement. In addition, electricity retailers can offer controllable capacity in the reserve markets. This means that in the future smart grid environment, a retailer's profit optimization is enhanced by the opportunity to pursue higher profits by exploiting DER along with the above-mentioned trading opportunities.

3.2 Main elements of the retail business

In order to describe such a complex and multistage problem as the problem of the retailer's profit maximization, it is convenient to approach it first from a wider perspective by a simplified presentation. Figure 3.2 gives an overview of the retailer operation in the smart grid environment by introducing the main elements of profit optimization, main interactions between them, and the division of the planning (operating) horizon applied in this work.

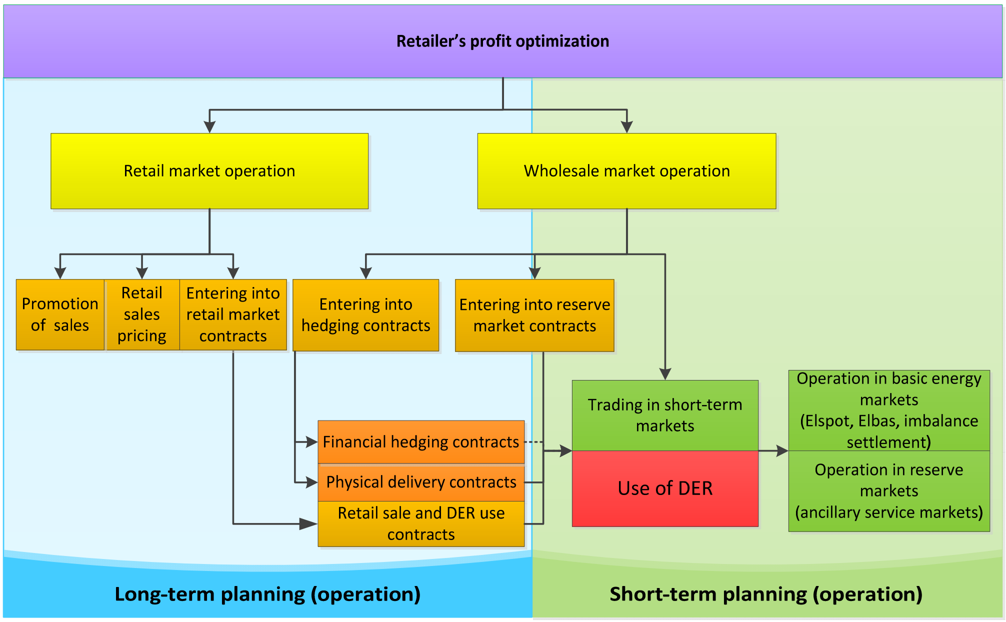

Figure 3.2. Electricity retailer operation in the smart grid environment and its division into long-term and short-term parts according to the planning (operating) horizon.

The tasks that take place within the long-term planning horizon are presented with a blue background, and the tasks within the short-term planning horizon with a green background. Within the long-term planning horizon, electricity retailers make strategic decisions in both the retail and wholesale markets in order to maximize the profits and minimize the risks of their operation. In the retail market, the focus is on the determination of an optimal sales pricing strategy and promotion of electricity sales. In the wholesale markets, the aim is in the determination of an optimal hedging strategy, which ensures an adequately low purchase (high sales) price for the energy traded. Hedging can be carried out by making fixed-price physical delivery contracts in the OTC (Over-The-Counter) market or by using financial products provided by the Nasdaq OMX commodities. In addition, the contracts related to the retail and wholesale market operation, such as reserve market agreements, are made within the long-term planning.

In the short run, electricity retailers trade and use controllable DER in parallel in order to establish the power balance and maximize their profits. Trading in the short-term markets can be divided roughly into two parts according to the segmentation of the markets. The first market segment consists of the basic energy markets, which in the Nordic markets include the day-ahead Elspot and intra-day Elbas markets and imbalance power trades through the chain of open deliveries. Although the imbalance settlement and the related imbalance power trades are not an actual marketplace in terms of making bids to the market, it is an essential part of a retailer's basic operation and is therefore considered among the basic marketplaces where retailers operate on a daily basis. The second market segment includes reserve markets that the system operator uses for the acquisition of controllable capacity in order to maintain the power balance of the power system. These markets are also generally referred to as balancing and ancillary service markets (Entsoe, 2015). This market segment provides additional profit-making opportunities for electricity retailers, and for the use of flexibly controllable DER units, but is not an essential part of their daily operations in the current operating environment.

The last main element of the retailer's profit optimization in the future smart grid environment is the use of controllable DER, which is later on simply referred to as the use of DER. The use of DER is planned and put into practice within the short-term operating interval, but the decisions made in the long-term planning of the retail business provide important inputs to this task. Entering into the required reserve market contracts, in other words, hourly market agreements, takes place within the long-term planning interval. The established hedging, and especially physical delivery contracts, produce inputs to the planning of electricity procurements in the short-term markets. In addition, the retail-side contracts, including sales and DER use contracts, have their impacts on the retailer's short-term operation. Especially the applied retail pricing model and constraints on the DER control defined by the contracts significantly affect the use of DER in the retailer's short-term profit optimization.

In practice, controllable DER capacity is used along with trading in the short-term power markets. There, a retailer can trade the available DER (energy) or use it to avoid trades in the wholesale markets. For instance, the retailer can sell available controllable DER capacity to the reserve markets, or use it to decrease the consumption instead of purchasing energy in the basic energy markets. Ultimately, the optimal way to exploit DER depends on the decisions made within the long-term planning, the prevailing operating and market situation, and the retailer’s opportunities to apply DER to its profit optimization.

Finally, the planning of the retail business can be divided into two main stages:

1. *Long-term planning;* Electricity retailers aim at ensuring the viability of the retail business through long-term planning by managing risks within acceptable limits and acquiring retail customers that provide sales income. Common methods to achieve these goals are determination of an optimal retail sales pricing model and hedging strategies. By these means, the retailer aims at balancing the risks and obtaining an adequate profit margin from the retail electricity sales. In addition, within the long-term planning, retailers enter into contracts such as reserve market agreements with Fingrid and DER use contracts with the customers, which enable the optimization of DER use in a short run.

2. *Short-term planning;* In the short term, electricity retailers aim at maximizing the profits of operation and acquire energy demanded by the customers. The main tool for this is trading in the physical power markets. In the future smart grid environment, retailers may also use controllable DER accompanied by trading. By these means, the retailers aim at procuring the demanded electricity at the lowest possible cost. In addition, the retailers can pursue higher profits by making additional trades, for instance offering available DER capacity in the reserve markets.

The following sections give an overview of the retailer’s profit optimization by introducing studies related to the long- and short-term profit optimization of the retail business. The basic principles and common approaches to the modelling and solving of the optimization problem are introduced. In addition, the short-term profit optimization approaches are reviewed and analysed within the scope of this study.

3.3 Long-term planning

In order to ensure the viability of the electricity retail business, electricity retailers have to plan their operation in the long term by considering various factors. In many cases, because of the unique characteristics of electricity, the rules and methods intended for other commodities cannot be applied as such to the planning of the electricity retail business. One of the key problems in the electricity business is that for economic and technical reasons, electricity can be stored only in limited quantities (Faria and Vale, 2011). In addition, the power balance between electricity production and consumption has to be maintained at every moment in the power system by controlling production- and consumption-side energy resources. Furthermore, the energy consumed by the end-users has to be delivered according to the demand (Gabriel et al., 2006; Hatami et al., 2009).

Because of these specific features of electricity, distinct market and operational models are needed, and specific requirements are set for the operation of the market parties.

Considering the electricity retailer operation, there are two requirements of particular importance. The first one, load obligation, binds the retailer to provide its customers (end-users) with the electricity they demand (consume). The second requirement is set by the system operator, and obliges each market party to constantly take care of its power balance between its electricity consumption/sales and procurement/production. In practice, the load obligation and responsibility to maintain the power balance require that the electricity retailer procure (trades) electrical energy the quantity demanded by the customers, regardless of the energy price in the wholesale markets. This combined with occasional high fluctuations in electricity prices exposes the retailers to risks, and highlights the importance of appropriate risk management. A common approach to the risk management is to aim at minimizing the electricity purchase costs by hedging well in advance. Typically, the aim is to minimize electricity procurement costs by fixing the purchase price of electricity in advance at as low a level as possible. In addition to the minimization of electricity procurement costs, the profit of the retailing also has to be maximized in order to maximize the total profits of the retail business. Here, a typical approach is the determination of an optimal retail sales price. Basically, this means defining an appropriate profit/risk margin that is included in the sales price.

Consequently, the long-term planning of the retail business can be boiled down to two practical objectives. The first one is to fix the purchase price of the demanded electricity at as low a level as possible. The second one is to define an optimal retail sales price that yields the maximum income from the retail sales. This requires consideration of numerous different factors simultaneously. For example, in order to define an optimal sales price that includes an adequate risk/profit margin and is low enough to attract customers, the retailer has to make estimations of the expected electricity purchase costs. On the other hand, the retailer’s sales incomes and risks depend largely on the applied retail pricing model. Therefore, establishment of hedging that provides an adequate hedge and satisfies the profit targets requires consideration of the applied retail pricing model and estimations of the sales incomes. Consequently, both of these tasks, minimization of the electricity procurement costs and maximization of the income, have to be studied simultaneously. In the following sections, the planning of the electricity retailing and hedging will be discussed in more detail based on a literature review.

3.3.1 Planning of the electricity retailing

The retail electricity is a highly standardized and homogeneous product that is delivered to the end-users always through the same channel, the local distribution network (Fleten and Pettersen, 2005). The requirement for the homogeneity of electricity limits the retailers’ opportunities to promote the sales by means of product differentiation (Woo et al., 2013). In addition, the tightening energy efficiency targets and the increasing environmental consciousness make the promotion of electricity sales even more challenging. Furthermore, the natural monopoly position of electricity distribution gives no place for retailers to gain competitive advantage by the delivery. Therefore, there are a rather limited number of tools that electricity retailers can use to enhance the electricity retailing. Figure 3.3 illustrates general approaches to enhance the electricity retailer's profit optimization by electricity retailing.

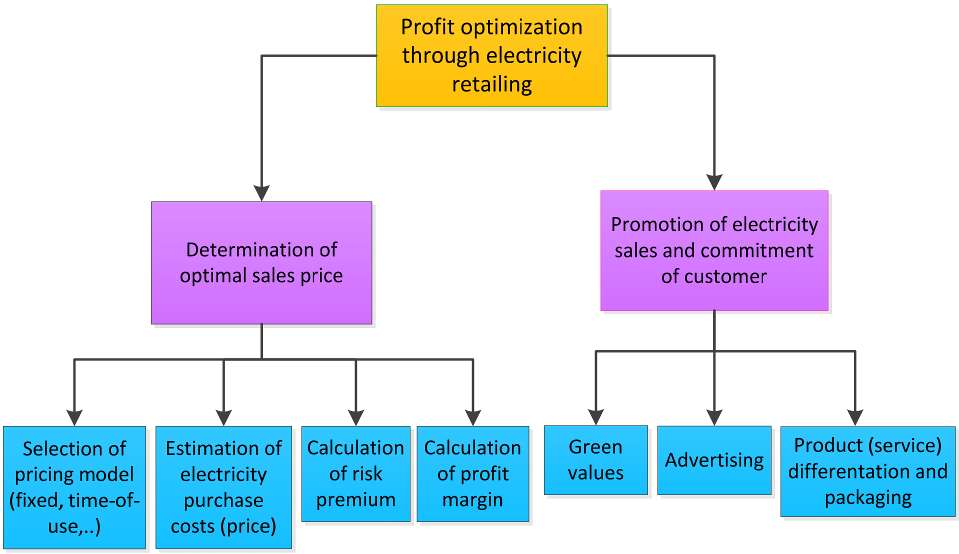

Figure 3.3. Common approaches to the retailer's profit optimization by electricity retailing.

In the literature, probably the most common approach to the electricity retailer's profit optimization by means of retailing is the determination of an optimal sales price. Thus, it is also discussed in this work in more detail than the other common approaches that include for instance the promotion of sales through green values, advertising, product differentiation, and packaging.

The determination of an optimal sales price plays an important role when considering maximization of the retail sales income, but also from the viewpoint of risk management. The basic problem in the retail sales pricing is how to find a balance between an adequate profit margin and a competitive price. On the one hand, the profit margin has to be high enough to ensure the viability of the retail business in the long term. On the other hand, too high a price does not attract new customers, and can even drive some customers to switch their retailer (supplier). The determination of an optimal sales price is generally approached by the selection of appropriate pricing model(s). After this, a baseline electricity sales price for the customers is determined. Finally, an appropriate risk/profit margin is calculated and added to the baseline sales price.

A retailer may use different models for retail sales pricing depending on the business strategy and profit targets. The main issues to consider when selecting an appropriate pricing model(s) are the impacts of the retail sales pricing on the retailer's risk exposure and the expected sales incomes. In this context, it also has to be considered that the applied sales pricing model has an effect on the end-users' consumption behaviour, in particular when dynamic pricing models are used. For instance the concept of demand price elasticity, which describes how changes in the retail price impact the end-users' electricity consumption, is used to measure these impacts.

Traditionally, electricity has been sold to end-users mainly with fixed-price tariffs, that is, flat contracts (Hajati et.al, 2011). Retailers may also use more dynamic tariffs, which can be categorized for instance according to (Faria and Vale, 2011) as time-of-use (TOU), real time pricing (RTP), and critical peak pricing (CPP) rates. When a retailer purchases electricity in the price-volatile wholesale markets and sells it to retail customers with flat contracts, the retailer bears all the risks that result from uncertainties in both markets (Bartelj et.al, 2010; Hajati et al., 2011). Then again, by using more dynamic tariffs on the retail side, a retailer can shift at least part of the price risk to the retail customers (Gabriel et al., 2006; Hajati et al., 2011). Moreover, dynamic tariff structures are generally seen as a potential way to promote the demand response.

Spot tariffs can be mentioned as an example of dynamic tariffs that have received increasing attention. Spot tariffs are based on the idea that the rate paid by the customer follows the price of electricity in the wholesale day-ahead (spot) market. In addition to the baseline rate defined by the wholesale market price, the customer pays a risk/profit margin to the retailer. Thus, when the retailer sells electricity to the end-user with a spot tariff, the customer bears the spot market price risk. Although a spot tariff transfers the spot market price risk from the retailer to the customer, the retailer faces other risks in the power markets. For instance, the retailer may face even a higher profile risk when spot tariffs are taken into use as a result of the changes emerging in the end-users' consumption behaviour. In other words, the retailer's estimated load profile (consumption) can deviate more from the established hedging, and result in an increasing exposure to the market price risk at certain times, because the end-users' consumption behaviour changes as a result of the implemented spot tariffs.

Various models, presented for instance in (Ahmadi et al., 2013; Bartelj et al., 2010; Procopczuck et al., 2007), can be used to calculate an appropriate risk/profit margin. The calculation is typically made based on the estimated risk exposure and electricity procurement costs (price), and/or considering the profit targets of the retailer. The aim is to make sure that the retailer obtains high enough margin that covers the income losses resulting from the possible materialization of risks and satisfies the profit goals. However, as (Bartelj et al., 2010) emphasizes, the retailer in a competed retailer market may not include a full risk premium in the retail sales price, which would cover all risks.

In addition to the determination of an optimal retail sales price, promotion of sales is another general approach to the profit optimization on the retail market side. However, compared with many other commodities, the specific features of electricity make the sales promotion rather difficult. Furthermore, the general energy efficiency targets and the increasing environmental consciousness make it even more challenging, and perhaps even somewhat questionable. Even so, the increasing environmental consciousness of customers can also be used to promote the sales through green (renewable) energy products. Indeed, many retailers have expanded their product mix for instance by offering purely wind and/or solar energy-based products to the customers. Retailers can also use other product/service differentiation and packaging means than green energy products. For instance advertising and other common sales promotion methods can be used to enhance the retail, although it may be challenging to apply common sales promotion methods as such to the electricity retail business, as emphasized above. In particular, the unique features of electricity, the low profit margins of the retail business, tight competition between the retailers, and the general energy efficiency targets make it challenging to obtain competitive advantage in the electricity retail business by retailing.

3.3.2 Planning of wholesale market operation

The market price risk caused by unforeseen fluctuations in electricity prices may result in high costs for the retailer even within a short time span. Therefore, in addition to the above-introduced approaches for profit optimization through the electricity retailing, electricity retailers aim at managing their risk in the wholesale markets. A universal approach to the retail's risk management is to aim at minimizing the electricity procurement costs by hedging in the long run. Most commonly, hedging is performed by using financial products and/or physical contracts. Along with the contractual hedging, for instance the determination of an optimal retail sales price may also be regarded as a common risk management tool, because it can be used to compensate for the possible realization of risk and the resulting high electricity procurement costs.

In the Nordic power markets, electricity retailers can carry out hedging by using financial products provided by the Nasdaq OMX commodities and by trading fixed-price physical delivery contracts both in the OTC market and bilaterally. Hedging by financial products has widely replaced traditional trade in physical delivery contracts. The financial products of Nasdaq OMX include futures, DS futures, options, and electricity price area differentials (EPAD) with a current trading time horizon of up to ten years, covering daily, weekly, monthly, quarterly, season, and annual contracts (Nasdaq 2015).

Although the electricity retailer aims at minimizing the risks in the long term by hedging, it may still be exposed to significant risks. One reason for this is that standardized hedging instruments typically do not make it possible to eliminate the whole risk exposure (Bartelj et al. 2010). For instance, the retailer's actual consumption can vary between different hours of the day, whereas hedging is carried out for some constant volume for a longer period of time. Therefore, the retailer is exposed to a profile risk, which means that the volume of unhedged electricity procurements varies in different hours according to the retailer's load profile (and the level of hedging). Furthermore, the retailers are exposed to risks against which they cannot hedge at all, or only very limitedly. These include for instance political and legislative risks. However, the consideration of these risks is outside the scope of this work.

Determination of an optimal hedging strategy requires an analysis of various factors. Time and volume aspects of hedging are generally regarded as the most critical ones. In addition, for instance consideration of volatility in prices and correlation between a load estimate and a forward price may help to improve the hedging strategy. The volume of hedging as a proportion to the retailer's estimated consumption is commonly described by the term 'hedge ratio.' A high hedge ratio indicates a low risk exposure, but also high hedging costs and limited opportunities to benefit from price movements. A low hedge ratio, instead, exposes the retailer to higher risks, but induces lower costs and limits less the opportunities to take advantage of forward price movements. Similarly as the hedge ratio, for instance the concept of open position is commonly applied to measure the volumetric risk in hedging. Open position describes the level of hedging as a difference between purchased contracts (physical and financial) and the forecasted electricity demand (Bartelj et al., 2010; Näsäkkälä and Keppo, 2005; Oum and Oren, 2010).

Optimal timing is one of the key challenges in hedging. On the one hand, when the time span between the hedging decision and the moment of delivery increases, also the uncertainty related to the forward prices increases. On the other hand, a retailer's opportunities to find an advantageous moment for hedging, that is, the time when the purchase (sales) price of electricity can be locked to the lowest (highest) possible level by hedging, increase along with the length of this time span. Retailers typically carry out hedging by increasing the hedge radio progressively when the moment of delivery approaches. The progressive increase in the hedge ratio allows to maintain the risk exposure caused by the volatility in electricity prices within acceptable limits, but also the profit-making opportunities offered by advantageous price movements will be preserved to a certain degree (Näsäkkälä and Keppo, 2005; Oum and Oren, 2010).

In addition to the volume and timing, the correlation between the electricity forward prices and the load estimate is considered an important aspect when carrying out hedging. If the correlation between the load estimate and the forward prices is positive, it is optimal to hedge earlier and prefer overhedging. On the other hand, a negative correlation can be seen as an additional hedging instrument that makes it optimal to postpone the hedging time and prefer underhedging. Thus, a high hedge ratio and/or early hedging time lowers the retailer's risks, but also decreases the profit-making opportunities. Correspondingly, a low hedge ratio and/or a postponed hedging time expose a retailer to higher risks, but offer higher potential profits (Näsäkkälä and Keppo, 2005; Oum and Oren, 2010).

Figure 3.4 illustrates a common hedging approach where hedging is carried out by increasing the hedge ratio progressively according to the tariff-based sales when the moment of delivery approaches.

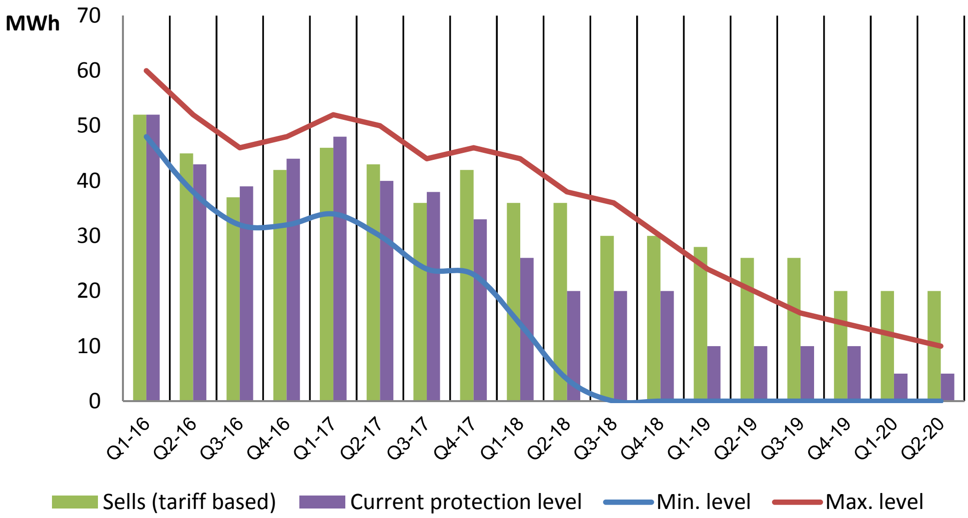

Figure 3.4. Example of an electricity retailer's progressively increasing hedging based on tariff-based sales.

The hedging strategy illustrated in Figure 3.4 is based on the idea that the retailer limits the risks to an acceptable level by defining minimum and maximum hedging levels according to the tariff-based sales, the retailer's risk preferences, and by considering the time aspect of hedging. The minimum and maximum hedging levels are indicated by blue and red lines, respectively. The retailer reduces the risk exposure when the moment of delivery approaches by adjusting the current hedging level closer to the estimated sales and by decreasing the spread out between the minimum and maximum hedging limits. Thus, also the retailer's open position (the difference between the hedging and the estimated sales) decreases when the trading period, in other words, the time period when the hedging can be carried out, becomes shorter. Consequently, the retailer's risks but also opportunities to benefit from the advantageous price movement decrease when the moment of delivery approaches.

Based on the above, we may summarize that by combining different hedging instruments retailers can hedge against most, but not all, risks. Moreover, in many cases it is not the optimal strategy to aim at hedging against all risks, because hedging induces additional costs and limits profit-making opportunities. Furthermore, the specific characteristics of the power markets typically do not allow to fully hedge against risks by using standard products of the market. Consequently, an optimal solution may be to only hedge against the most significant and probable risks.

3.3.3 Literature review on long-term planning

The history of competed electricity markets is rather short; the power sector was opened up to competition only in the 1990s, or later, depending on the geographical region. Consequently, the literature related to the electricity retail business is rather scarce compared with many other research areas with a longer history. Over the recent years, developments in the electricity markets and the increasing importance of electricity retailers as market intermediaries have received increasing attention. As a result of this, a number of studies related to the electricity retailer's profit optimization have emerged, although this group is still not very large. In addition, numerous studies can be found that are closely related to the topic, for instance on generators' and large consumers' strategic planning.

This brief literature review introduces common approaches to the long-term planning of the retail business and addresses the key modelling aspects based on studies that are found the most interesting ones from the perspective of this study. The studies are categorized under long- and short-term planning topics based on the principles presented in Figure 3.2. Studies that mainly focus on the strategic planning of the retail business, for instance through various hedging strategies and retail sales pricing approaches, are placed within the category of long-term planning studies and introduced here. The studies related to the short-term planning will be introduced later in section 3.4.4. Some of the long-term planning studies also cover strategies that, from some perspectives, can be considered to belong to short-term planning, because they examine for instance trading in the day-ahead and other real-time markets. Still, these studies also include analysis of risks related to the retailer's contract portfolio or other similar aspects that are generally regarded as long-term planning tasks. Therefore, also these studies have been categorized as long-term planning studies in the literature review.

The literature on the long-term planning of the electricity retail business provides a variety of approaches to model the electricity retailer's profit optimization problem and to accomplish the main objective of the retailer, that is, maximization of profits. This main objective can also be expressed, for instance, as the objective(s) of sales income maximization and/or electricity procurement cost minimization. In addition, risk management is universally included in the main objectives of long-term planning studies.

The majority of the studies in the literature review aim at the maximization of profits by the determination of an optimal hedging strategy and/or an optimal retail sales price. For instance (Hatami et al., 2009; Hatami et al., 2011) propose models for the determination of optimal sales price and energy procurement strategies, (Bartelj et al., 2010; Prokopczuk et al., 2007) discuss optimal risk premiums, (Ahmadi et al. 2013; Kettunen et al., 2010; Nazri and Foroud, 2013; Xu et al., 2006) introduce optimal contract portfolios and energy procurement strategies, and (Näsäkkälä and Keppo, 2005; Oum and Oren, 2010) present advantageous hedging strategies. Although there are certain similarities in the main objectives and approaches of these studies, the assumptions made, the energy procurement options chosen, and other specific features of the modelling may vary significantly. For instance (Hatami et al., 2011) proposes a decision-making framework with a variety of energy procurement options including call options, interruptible contracts, self-generation, and trades in the day-ahead and real-time markets, whereas (Gabriel et al., 2006) focuses on determining an optimal strategy for future loads by considering only the spot market-clearing price.

In the long-term planning studies, the retailer's profit optimization is typically approached by analysing the risks related to the retailer's electricity procurements in the wholesale markets. The studies presented for instance in (Bartelj et al., 2010; Hatami et al., 2009; Hatami et al., 2011; Kettunen et al., 2010; Prokopczuk et al., 2007) agree almost universally that volume and price risks are among the main risks faced by an electricity retailer. In addition, the time aspects of long-term planning, and in particular, the timing of hedging and its impacts on the retailer's risks, are seen among the key issues. For example (Bartelj et al., 2010) has taken the approach of contract offer maturity risk, (Gabriel et al., 2006) the settlement risk, and (Näsäkkälä and Keppo, 2005) the optimal hedging strategy approach to study the time aspects of long-term planning.

Most commonly, the risks in the electricity markets are modelled by the volume or financial risk in the contract portfolio under consideration. It is generally recognized that the risks faced by the retailer have to be measured by some feasible method, which should be selected based on the specific purpose of use. (Hatami et al., 2009; Prokopczuk et al., 2007) highlight that all commonly used financial risk measures may not be appropriate in the electricity market environment, where significant downward and upward movements (i.e. major losses) may occur. According to these studies, for instance standard deviation and variance have failed to be adequate risk measures in the electricity market environment. Instead, for example (Hatami et al., 2009; Bartelj et al., 2010) have used conditional value-at-risk (CVaR), (Prokopczuk et al., 2007) Risk Adjusted Return on Capital (RAROC) and (Ahmadi et al. 2013) Expected Downside Risk, to successfully measure the financial risk of an electricity market party in the power markets.

In addition to financial risk measures, volumetric risk measures are used in many studies to describe the retailer's risk exposure that results in demand forecast inaccuracy. (Bartelj et al., 2010) applies the concept of open position to describe the difference between the purchased contracts and the short-term demand forecast, whereas (Näsäkkälä and Keppo, 2005) uses the concept of hedge ratio to describe the hedging size as a proportion to the load estimate. In general, volumetric risk measures are relatively simple to use but still effective and reliable for many modelling purposes, although they may not be able to measure the impact of price uncertainty such as financial risk measures.

The competition between retailers is also found to be one of the key issues to be addressed in the modelling of the retailer's profit maximization in the long run. A common approach to model the competition between arrival retailers is to consider how the retail sales price affects the retailer's sales volume. For instance (Ahmadi et al., 2013) uses a stepwise price-quota curve, (Hatami et al., 2009) a market share function and (Gabriel et al., 2006) an acceptance function to model the competition. Basically, all these functions describe the relationship between the retail sales price offered by the retailer and the realized sales volume to the end-users.

In general, for instance the competition between retailers is modelled by rather uniform principles. Nevertheless, the modelling assumptions differ, for instance with respect to the retailer's market power, that is, the influence of the retailer's bidding action on the market price. For instance, (Hatami et al., 2009) introduces an approach that includes a price-taker retailer whose bidding actions do not affect the pool price, whereas (Ahmadi et al., 2013) considers a price-maker retailer whose purchases raise the price. Also other common modelling assumptions, for instance considering the type of applied sales tariffs and price responsiveness of the customers, vary depending on the study.

The actual modelling and solving of the retailer's long-term profit maximization problem is generally based on the modelling of retailer's electricity demand and price distributions. The majority of the studies apply some stochastic models for the purpose. For instance (Ahmadi et al., 2013) has applied a Roulette wheel mechanism and Lattice Monte Carlo simulations, (Hatami et al., 2009; Kettunen et al., 2010) GARCH models (Generalized AutoregRessive Conditional Heteroskedasticity), (Hatami et al., 2011) an ARMA approach (autoregressive moving average), and (Prokopczuk et al., 2007) SARIMA time series (Seasonal Autoregressive Integrated Moving Average) to model the uncertain pool price and the retailer's demand.

Examples of alternative modelling approaches can also be found in the literature, which, instead of complex stochastic modelling, simplify the modelling problem into a more deterministic one. For instance (Näsäkkälä and Keppo, 2005; Oum and Oren, 2010) make assumptions about a specific electricity price and quantity dynamics, and based on them, generate models for optimal static hedging strategies. Although stochastic models may allow more detailed modelling of the problem, the advantage of these simplified approaches is that they enable a direct analytic solution of the problem under study.

Nevertheless, in the case of stochastic modelling problems, it may be challenging, or even impossible, to find a global optimal solution by using analytic methods, and numerical methods may lead to an excessive computational burden. Therefore, it is often necessary to make some simplifications and apply specific problem-solving methods so that it is possible to solve the problem by taking some analytic, heuristic, or modular approach. For example (Ahmadi et al. 2013) converts the stochastic optimization problem first into its respective deterministic equivalents and then solves it by applying the Benders decomposition technique. (Hatami et al., 2009; Hatami et al., 2011) also adopt a similar approach, but solve the decomposed problem by using a branch-and-bound algorithm. As (Hatimi et al. 2011) points out, it is emphasized that although these kinds of problem-solving approaches can find an acceptable suboptimal solution, they do not guarantee a global optimal solution.

The studies under review report various results, which are obviously case dependent and may vary according to the markets, assumptions, and other specific features of the modelling. Most studies have found some correlations between the retailer's risks and expected profits. For instance (Ahmidi et al., 2003; Bartelj et al., 2010) report that when the concern of risks increases, the expected profit decreases. Based on that (Ahmidi et al., 2003) also states that the retailer could significantly reduce its risk level at the cost of reducing the expected profit. (Hatami et al., 2009; Hatami et al., 2011), again, have found that the retailer is at a high risk when it purchases its demand only from the spot market, but when different power supply options are used, the risk can be managed considerably better and higher profits can be expected. The results of (Näsäkkälä and Keppo, 2005) indicate that over (under) hedging is an optimal strategy when the load estimate and the forward prices are positively (negatively) correlated, and that a positive correlation between the load estimate and forward prices have a pre-emptive impact on the hedging time, whereas a higher volatility postpones the hedging decision. Further, (Prokopczuk et al., 2007) suggests that differences in customers' load curves lead to quite different assigned risk premiums, and states that in open electricity markets the risk premiums have to be calculated close to the profit frontiers to remain competitive.

The studies examined within this review represent only a fraction of long-term planning studies. However, they can be considered illustrative examples of common problem modelling approaches, and were therefore included in this review. Although one may also find many other interesting studies on the long-term planning of the retail business, the objective of this section is only to give an overview of certain common modelling approaches, key modelling aspects, and typical results for the further modelling of the retailer's profit optimization problem. Therefore, more detailed considerations and analyses about long-term planning of the retail business are outside the scope of this work.

3.4 Short-term planning

The short-term planning of the retail business focuses on the optimal management of the electricity procurements close to the delivery, whereas the long-term planning aims to ensure the viability of the retail business by the risk management and the optimal retailing strategy. In the present power markets, the management of electricity procurements close to the delivery typically refers to trades in the short-term markets. In the future smart grid environment, the retailers can additionally use controllable DER for the same purpose, which introduces new elements to the short-term planning of the retail business.

The decisions made within the long-term planning serve as the basis for the further planning of the electricity retail operation in the short term. On the one hand, the long-term planning decisions can limit the retailer's short-term operation, but on the other hand, these decisions can also improve the profit-making opportunities. Therefore, the long-term planning decisions have to be taken into account in the background of short-term planning and operation. Next, the role of long-term planning as a basis for the short-term planning is examined in more detail. After that, basic strategies for the short-term planning are introduced in brief. This is followed by a literature review that summarizes general approaches for short-term planning and analyses them as a basis for the modelling of the retailer's short-term profit optimization in the smart grid environment.

3.4.1 Long-term planning as a basis for short-term planning

In general, the short-term planning of the retail business focuses on the retailer's final operations needed for the maximization of the expected profits within the constraints set by the retailer's load obligation and requirements to maintain the power balance. The main guidelines for the retailer's short-term operation come from the decisions made during the preceding long-term operation. For instance the applied retail sales pricing model, hedging strategies, and the contractual planning in general have to be considered as a basis for the planning of short-term operation.

The applied retail sales pricing model is one of the central long-term planning decisions that affect the retailer's short-term operation. The sales price directs the customer's consumption behaviour, and thereby has an effect on the retailer's load profile. In addition, the applied retail sales pricing model has an impact on the retailer's ability to indirectly control its customer's consumption. If some dynamic retail pricing model is applied, the retailer can control, at least to some extent, its customers' consumption through variable retail prices. This is referred to as price-based demand response. Instead, when only a flat tariff is used, the retailer does not have this opportunity. Thus, the retailer's options to affect the end-users' electricity consumption, and thereby the total sales volumes, vary depending on the pricing model applied.

In addition to the price-based demand response, the retailer can manage its end-users' electricity consumption and thus also its own power balance by using other than price-based DR applications. These are commonly referred to as incentive-based demand response and demand side management (DSM). For example, a retailer can pay a fixed compensation to the customers, which allows the retailer to control the customer loads or other DER units within the limits set by the customer. According to the basic assumption of this doctoral dissertation, in the future smart grid environment, the retailer can control its customers' DER units by applications of this kind. From a practical point of view, this operation requires contracts that define for instance compensations paid to customers and constraints on control measures taken by the retailer. These contracts have to be made with the end-users in advance, already within the long-term planning horizon.

The hedging strategy is also included in the key long-term planning decisions that affect the retailer's short-term operation. From the perspective of short-term planning, it is of significance whether the hedging is made by using financial or physical delivery contracts. Although the financial hedging affects the price of the energy paid by the retailer, it does not have an effect on the retailer's physical electricity procurements and the resulting power balance. Therefore, financial hedging does not have a direct impact on the retailer's short-term operation, although it affects the retailer's risks. On the other hand, the physical delivery contracts lead to physical trade of energy, and thus, they have a direct impact on the retailer's power balance and consequently, on the need to manage electricity procurements within the short-term operation. Figure 3.5 presents an example of long-term hedging as a basis for the retailer's short-term operation.

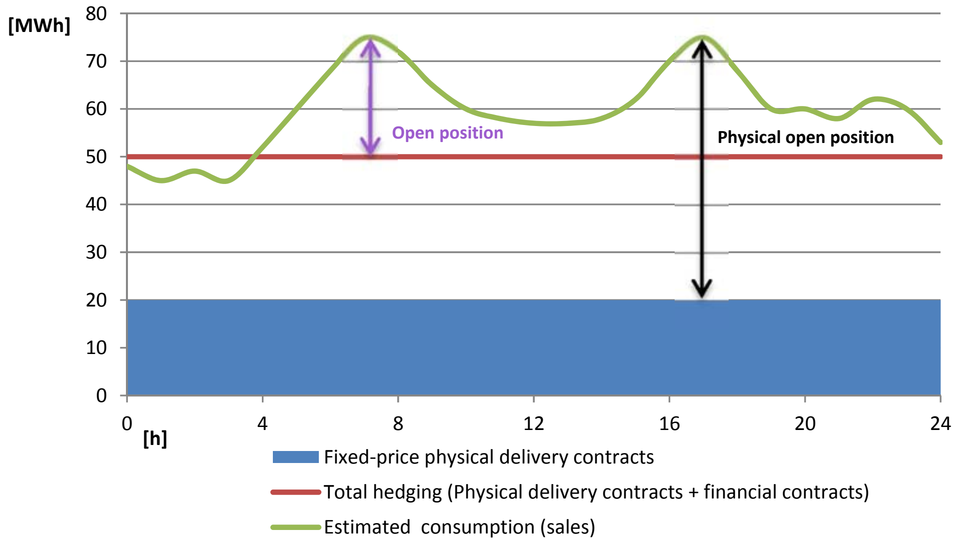

Figure 3.5. Electricity retailer's long-term hedging as a basis for the short-term operation.

Figure 3.5 presents the retailer's fixed-price physical delivery contracts by blue; the red line indicates the total level of hedging including both physical delivery and financial contracts, and the green line the retailer's forecasted consumption (sales). The illustration shows that the retailer has made long-term physical delivery contracts for 20 MWh and financial contracts for 30 MWh, which results in a total hedging of 50 MWh. This means that the retailer has secured a fixed purchase price for the amount of 50 MWh for each hour of the day. Although the retailer has hedged the purchase price for a volume of 50 MW in advance, only 20 MWh of physical electricity has been purchased. The rest of the energy demand has to be purchased with the current area price in the short-term markets.

From the perspective of the retailer's short-term operation, the situation illustrated in Figure 3.5 is significantly different than if the whole hedging volume, a total of 50 MWh, is covered by using physical contracts. Now, the retailer has to purchase the volume of the corresponding financial hedging, a total of 30 MWh, more in the short-term markets than if the hedging was carried out with physical delivery contracts. Still, the total impact of the hedging on the retailer's profits is the same in both cases, with the exclusion of the impacts of different area price risk exposures. In general, the energy that is traded under physical delivery contracts is purchased (or sold) by the retailer at the area price, whereas financial hedging contracts such as DS futures, futures and options are cash-settled against the system price. Therefore, the physical delivery contracts themselves provide a hedge against the area price risk, whereas in the case of financial contracts the retailer has to use EPADs (Electricity Price Area Differentials) in order to obtain the corresponding hedge.

Since the short-term planning of the retail business focuses on the management of physical electricity procurement, it is convenient to approach its modelling through the volume of the retailer's power balance, or more precisely, the volume of estimated power imbalance. For this purpose, the concept of physical open position is defined. However, the idea behind the concept is first introduced in brief.

Studies in the field of long-term planning of the retail business have adopted for instance such concepts as open position and hedge ratio to model the retailer's (volume) risks. (Bartelj et al., 2010) defines the open position as a difference between the purchased contracts (physical and financial) and the short-term demand forecast. Thus, open position describes the amount of unhedged electricity procurements compared with the estimated consumption. In the example of Figure 3.5, the retailer's estimated consumption during the examination day varies between 45 and 75 MWh, whereas the total hedging level is set to 50 MWh. This results in an absolute hourly open position between 5 and -25 MWh, and a relative open position of 10 % and -50 %, depending on the hour of the day. The highest value of the retailer's open position, -25 MWh at 7 a.m. (and 5 p.m.), is illustrated in the figure by a purple double arrow.

The open position is applicable to the modelling of the retailer's current hedging level, but it does not quantify the retailer's prevailing power balance, or the need for physical electricity procurements in the short-term markets, and the resulting risk that is referred to as imbalance risk in the context of this work. Therefore, the concept of physical open position is defined in order to model the retailer's imbalance risk in the short-term profit optimization. To the best of the author's knowledge, this concept has not been used in the literature of the field, and thus, a standard definition has not been found. Therefore, the physical open position is defined, according to the same principle as open position but adjusting the definition applicable for measuring the retailer's risks within short-term operation, as the difference between the retailer's current physical electricity procurements and the recent short-term demand forecast. Both the physical delivery contracts and the trades made so far in the short-term markets are included in these current physical procurements.

The concept of physical open position is developed especially to model the retailer's imbalance risks in the short-term profit optimization. It also describes the retailer's need for physical electricity procurements simply and unambiguously. In addition, financial hedging that does not affect the retailer's physical power balance within the short-term operation is separated from the physical electricity procurements in the problem modelling. For example, in the example of Figure 3.5, the retailer's estimated consumption during the examination day varies between 45 and 75 MWh, and a total of 20 MWh of physical electricity has been purchased. This results in a physical open position between -25 and -55 MWh expressed in absolute values depending on the hour of the day. The highest value of the retailer's physical open position, -55 MWh at 5 p.m. (and 7 a.m.), is indicated by a black double arrow.

Based on the above, it can be summarized that decisions made in the long-term planning provide various inputs to the short-term planning of the retail business. In order to derive a comprehensive model for the retailer's short-term profit optimization in the smart grid environment, these inputs have to be addressed. Moreover, it is important to consider the differences between financial and physical hedging contracts. When the retailer has carried out financial hedging, the actual physical energy has still to be purchased from short-term markets, unlike in the case of using physical delivery contracts. Furthermore, the financial hedging contracts are cash settled against the system price, and therefore, additional hedging by EPADs is needed in order to hedge against the area price risk. Again, physical hedging contracts that lead to physical electricity delivery with the agreed price also provide a hedge against the area price risk. Consequently, it is important to make a difference between financial and physical hedging when planning and modelling the retailer's short-term profit optimization. For this purpose, the concept of physical open position was defined. It can be used to simply model the retailer's physical electricity procurements relative to the estimated consumption.

3.4.2 Basic strategies for short-term profit optimization

An electricity retailer can use different strategies for its short-term profit optimization. In practice, the retailer's risk preferences, but also other issues such as the characteristics of the markets and tools available for profit optimization impact on the selection of the strategy. A retailer can aim at minimizing the risks, for instance, by minimizing the physical open position. Alternatively, the retailer can take more risks and aim at higher profits, for instance, by managing the physical open position according to the estimated market movements and searching for profitable "buy low, sell high" opportunities.

In general, a risk-averse retailer aims at minimizing the risks, for instance by maintaining the physical open position close to the zero level. The aim is thus to avoid imbalance power trades, and the risk caused by the typically high volatility of imbalance power prices compared with the spot prices. On the other hand, a risk-taker retailer generally aims at higher profits by applying more risk-taking profit optimization strategies such as market timing. In this case, the target is to find optimal purchase or sales opportunities based on the estimated market price movements. Simple examples of risk-averse and risk-taker retailer trading strategies are presented in Table 3.1 and Table 3.2, respectively. For the sake of simplicity, long-term hedging is not considered in the example, and the examination is made for one delivery hour.

Table 3.1. Example of a risk-averse retailer's trading strategy

Marketplace	Forecasted market price [€/MWh]	Forecasted consumption [MWh]	Physical open position (prior to trading) [MWh]	Energy traded in the market [MWh]
Elspot	50	60	-60	60
Elbas	30	65	-5	5
Imbalance settlement	70	65	0	0

Table 3.2. Example of a risk-taker retailer's trading strategy

Marketplace	Forecasted market price [€/MWh]	Forecasted consumption [MWh]	Physical open position prior to trading [MWh]	Energy traded in the market [MWh]
Elspot	50	60	-60	50
Elbas	30	65	-15	20
Imbalance settlement	70	65	5	-5

Table 3.1 shows that the risk-averse retailer aims at purchasing energy based on the consumption forecasts in the Elspot and Elbas markets precisely for the volume that corresponds to the retailer's physical open position prior to the trades in the particular market. This way, the retailer aims at minimizing the risk related to uncertainties in market prices, although this is not the optimal trading strategy according to the forecasted prices. Table 3.2, again, shows that the risk-taker retailer aims at taking advantage of the forecasted price differences between different marketplaces. In this case, the retailer takes some risk, but still avoids a high risk, and therefore purchases slightly less than indicated by the physical open position in the Elspot market. The purchase of the rest of the demanded energy is postponed to the following Elbas market, where the price is estimated to be lower than in the Elspot market. In addition, the risk-taker retailer purchases slightly more energy in the Elbas market than is required to obtain the physical open position in balance. This way, the retailer aims at obtaining a profitable sell-back opportunity in the imbalance settlement, where the forecasted price is higher than in the spot markets.

Based on the above example, we may state that the more the retailer is willing to take risks, the higher proportion of the electricity purchases is postponed from the Elspot to the Elbas market, and the higher amount of excess energy is purchased from the Elbas market in order to obtain a profitable sell-back by imbalance power trades. In practice, for instance limitations on the market players' allowed imbalance deviations and liquidity of the markets may impose constraints on the applied trading strategies. Furthermore, especially the risks related to uncertainties in the price and demand forecasts have to be considered. If the forecasted prices and consumptions of the above example materialize, the risk-taker retailer gets greater profits than the risk-averse retailer. However, if there are inaccuracies in the forecasted prices and/or consumptions, the situation can be opposite. Although the example is rather simple, it illustrates different basic strategies that the retailers can use for trading in the short-term markets, and shows how the retailer's risk preferences may impact on the applied trading strategy. Although the retailer's risk preference have a significant influence on the chosen operation strategy, there are also many other factors that affect the planning of the retailer's short-term operation. These are discussed in more detail in the following.

3.4.3 Electricity price and demand uncertainties

One of the basic problems in the planning of the electricity retail business is uncertainty related to the future electricity price and consumption. In the long run, the inherent uncertainty associated with the future price and consumption is high and highlights the importance of appropriate risk management. Although the future price and consumption can usually be forecasted more accurately within the short-term operation interval, consideration of the price and demand uncertainties is still of importance. The correlation between the forecasting horizon and the forecasting accuracy is illustrated in Figure 3.6.

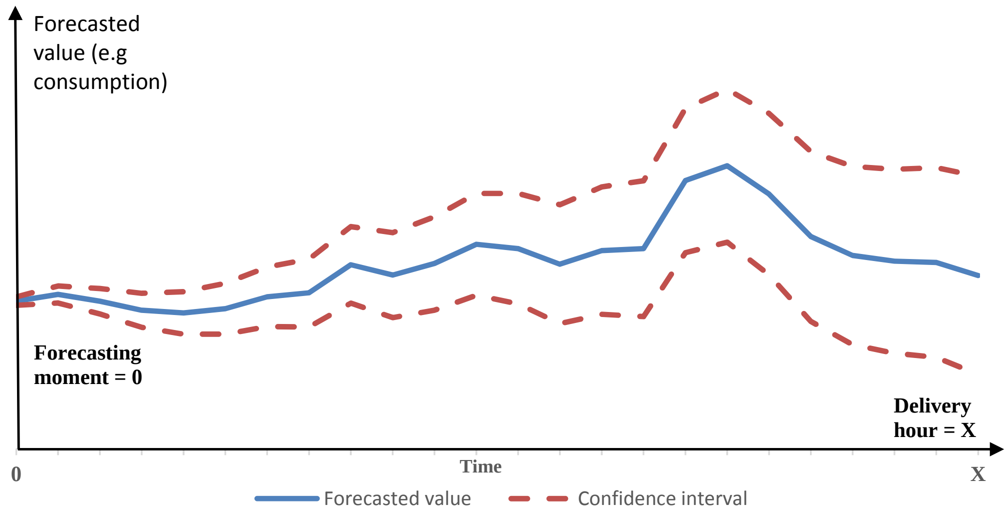

Figure 3.6. Correlation between the forecasting time period and the forecasting accuracy.

Consumption forecasts can be regarded as the main input data for the planning of the retailer's short-term profit optimization. Based on the consumption forecasts, the retailer estimates the volume that has to be purchased or sold in order to meet its load obligation. Price forecasts, again, can provide useful input data for identification of advantageous marketplaces and moments for trading, although the considerable uncertainty related to price forecasts poses challenges of its own.

Customers' future electricity consumption can usually be forecasted with a rather good accuracy, if the forecasting horizon is short enough, and accurate enough input data are available. For instance temperature forecasts, customer load profiles, and measurement data on customers' electricity consumption are typically used as the input data. Especially the customer type load profiles, which describe the customers' seasonal consumption patterns, at least with a certain accuracy, play an important role in the short-term consumption forecasting. By taking into account the above-mentioned aspects, and other factors that affect the end-users' consumption, a retailer can quite accurately forecast the future electricity consumption within the short-term operation horizon. Moreover, as a result of the large-scale installation of AMR meters, electricity retailers have a better access to the AMR data of the customers' recent electricity consumption. These customers' hourly consumption data can be used, for instance, to develop more accurate customer type load profiles, and thus improve the accuracy of the consumption forecasts. Still, it has to be taken into account that there are always certain stochastic components that produce some inaccuracy to the consumption forecasts (Mutanen et al., 2011; Valtonen et al., 2010b).

Traditionally, forecasting of future electricity prices has been a less familiar area for electricity retailers than the consumption forecasting. Further, price forecasting is typically considered a more complex task than consumption forecasting. Unlike electricity demand series, electricity price series typically exhibit variable means, major volatility, and significant outliers. In addition, as a result of the extreme price volatility reflected in price spikes, electricity price forecasting faces many challenges and includes considerably high uncertainties. The specific characteristics of the markets also have a significant impact on price movements, and thereby on the accuracy of the price forecasts. For example, electricity prices can typically be forecasted more accurately in the Elspot markets than in the balancing power market. This can largely be explained by the specific characteristics and lower trading volumes of the balancing market compared with the Elspot market; the balancing market exhibits a higher price volatility and frequency of price spikes than the Elspot market (Voronin, 2013).

As presented above, the uncertainty related to price forecasts is usually considerably high, which can make their efficient use in the planning of the retail business challenging. Nevertheless, promising price forecasting applications have recently been introduced, which can also relatively reliably estimate the occurrence of price spikes, generally considered among the most difficult events to forecast. For instance (Voronin, 2013) presents a hybrid price forecasting model intended for forecasting of normal-range prices and price spikes in competitive markets. Such a model can provide an electricity retailer with an effective tool for operation planning.

The consideration of uncertainties related to the forecasts is highly important in the planning of the retail business. Actually, the uncertainty related to the forecasts should be taken into consideration already when planning the profit optimization strategies. In this way, the retailer can use a more risk-taking profit optimization strategy if consumption and prices forecasts are accurate, whereas the use of a more risk-averse strategy is preferable if the forecasts include high uncertainties. By this approach, the retailer can compensate for the risks caused by the uncertainties by applying a more risk-averse profit optimization plan, although this also limits the retailer's profit-making opportunities.

In general, fluctuations in electricity prices and customers' electricity consumption are a sum of various factors. Therefore, it is usually preferable to examine the price and consumption behaviour as a whole rather than through individual factors. For instance, consideration of demand price elasticity can provide better understanding of the dynamics between prices and consumption. This, again, can help the retailers to better assess the risks of different operation models and to plan advantageous short-term operation strategies.

Demand response, which is closely related to the demand price elasticity, is also among the important aspects to be considered. Demand response has an impact, for instance, on the market price dynamics and may thus have a significant influence on the retailer's risks. The existence of DR in the markets generally reduces price volatility and cuts the price spikes thereby decreasing the retailers' risks. On the other hand, emerging or occasional demand response can be difficult to forecast, and may thus also complicate the planning of the retailers' short-term operation, and expose the retailer to higher power imbalances. Nevertheless, DR has mostly favourable impacts on the power markets and market players' operation. Moreover, DR will play an increasingly important role in the future smart grid environment, because it can balance the variations in consumption and prices caused by the increasing proportion of intermittent renewable production.

The increasing proportion of intermittent renewable generation, better opportunities for the efficient use of DER, but also other developments in the operating environment may significantly influence the dynamics of demand and prices. It is important to consider these changes in order to manage the risks they cause, and aim at exploiting the emerging profit-making opportunities instead. This also highlights the importance of the controllable DER in the future smart grid environments. These resources can function as an additional tool for risk management and an alternative for trades in the short-term markets. However, this requires appropriate methodology and strategies that allow the retailer to exploit the profit-making opportunities available and manage the risks involved in the emerging smart grid environment. The next section examines in more detail different methodological approaches that are commonly used in the literature to the retailer short-term profit optimization, and analyses them within the scope of this work.

3.4.4 Literature review on short-term planning

The emphasis in this literature review is on illustrating the variety of modelling approaches that focus to the retailer's short-term profit optimization. A further target of the review is to validate the novelty of this study. Moreover, among the objectives is also to provide a basis for the modelling of the retailer's short-term profit optimization in the future smart gird environment by investigating and outlining the most relevant general modelling approaches and aspects from the perspective of this work.

Recently, electricity retailers' role as market intermediaries, traders in the short-term market, and as potential market parties to adopt DR and market-based DER control applications has gained in importance and received increasing attention among the researchers. Thus, also the number of studies on the retailer's profit optimization has increased. Nevertheless, the studies focusing on the short-term planning of the retail business are few in number. Moreover, most of the studies address retailers' operation in the current markets and operating environment, while the aspects of the future smart grid environment have received less attention so far.

In general, the studies that can give useful data for the development of comprehensive methodology for the retailer's short-term profit optimization in the smart grid environment include, for instance, the following categories:

- operation planning and bidding strategies of retailers, generators, and large consumers
- conceptual models related to the use of DER
- economic analyses of DER applications
- topics of market-based DR, DSM, and DER applications
- other related topics such as pricing models, tariff structures, and market reviews

The studies incorporated in this review focus on the retailer's short-term profit maximization in the current operating conditions or in the future smart grid environment. In practice, electricity retailers can operate both as buyers and sellers in the wholesale markets. In addition, as pointed out in (Herranz et al., 2012), there is a clear parallelism between the optimization methodologies of energy buyers and sellers. Therefore, not only the literature on retailers' short-term profit maximization, but also studies considering sellers' or large buyers' profit maximization, are studied within the scope of the review. In addition, studies that present economic analyses, market-based applications of DR, DSM and DER, and other smart grid aspects are under review. Although also other related topics including various pricing models, tariff structures, and market reviews can provide useful data, less attention is paid to them here.

The approaches to the modelling and solving of the retailer's short-term profit optimization problem vary significantly, although the main objective is usually the same, that is, the profit maximization. In this review, the studies regarding optimal bidding strategies consist mainly of papers that focus on models applicable to the Nordic markets. Again, only some of the most interesting studies that consider future developments and transition into the smart grid environment are included in this review. This is because there is an abundance of literature on the topic, yet there are very few studies on the retailer's short-term profit optimization in the smart grid environment. Therefore, mainly topics that are closely related to the DR, DSM, and DER, and the respective economic analyses and operational and business models, are addressed in this category of studies.

The reviewed literature generally acknowledges that in the competed electricity markets, an appropriate profit maximization model (strategy) may give essential advantage over other retailers. However, a variety of spot market designs and market rules, varying operating conditions, and other such factors can make it difficult to define general profit maximization models that are applicable to different markets and operating environments. Consequently, as for instance (Li et al., 2011) emphasizes, the profit maximization has to be developed based on the specific features of the present operating and market environment. Moreover, according to (Herranz et al., 2012), the variety of market structures might also be the reason why a number of different profit maximization approaches have been proposed.

The examined studies universally consider the day-ahead markets as the main marketplace for physical electricity trading. However, there are fewer studies that consider other short-term markets such as intraday, balancing, and ancillary service markets. Some short-term planning studies such as (Beraldi et al., 2011) also study at the strategic level an opportunity to procure electricity through bilateral contracts. In general, bilateral trading can be placed under long-term planning as the contracts are typically made well in advance of the moment of delivery. Nevertheless, physical delivery contracts have a direct effect on the planning of electricity procurements in the short-term markets. Therefore, it is pointed out that the market environment itself and the preceding decisions made in the long-term planning play an important role as a basis for the planning of short-term operation.

One of the most popular approaches to the retailer’s (or producer’s and consumer’s) short-term profit maximization is the determination of an optimal bidding strategy, as shown for instance in (Li et al., 2011; Klaboe and Fosso, 2013). According to (Klaboe and Fosso, 2013), the literature on this topic can be categorized under the topics of separate bidding and coordinated bidding, where the latter is also often referred to as sequential bidding. Separate bidding considers bidding in the day-ahead market only, or in some other particular market. Coordinated bidding, again, refers to bidding sequentially in different short-term markets. Irrespective of the bidding strategy chosen, the objective is to maximize the financial results while keeping the risks at an acceptable level. As (Klaboe and Fosso, 2013) points out, this typically comes down to decisions on where (in which market) to buy or sell energy, what prices should be set for the bids, and/or what volumes should be bid in the market. In addition, coordinated bidding strategies usually aim at benefiting from the arbitrage opportunities between different short-term markets.

Alternatively, the studies introducing optimal bidding strategies can be classified based on the modelling approach adopted. For instance, (Li et al., 2011) classifies the optimal bidding approaches into single market player optimization models, game-theory-based models, agent-based models, and hybrid models, Figure 3.7.

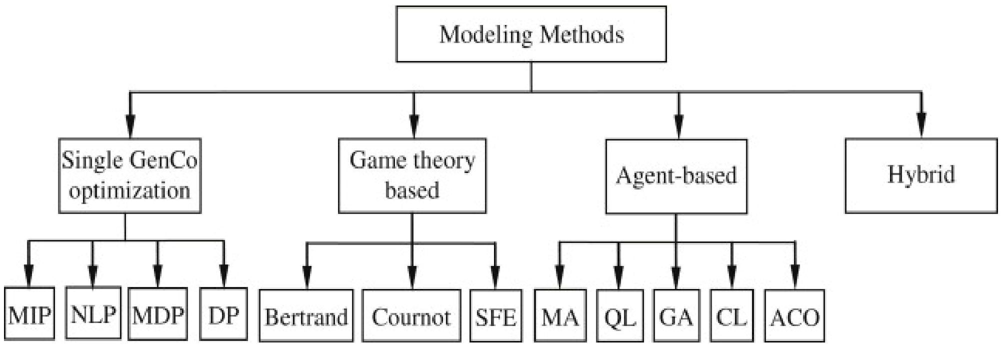

Figure 3.7. Modelling methods for bidding electricity in the spot market (Li et al., 2011).

Single Generation Companies' (GenCo) optimization models include Mixed Integer Programming (MIP), Nonlinear Programming (NLP), Markov decision process (MDP), and Dynamic Programming (DP) models. The game theory models apply, for instance, different competition rules such as Bertrand competition, Cournot competition, and Supply Function Equilibrium (SFE). The agent-based models can be categorized according to different learning algorithms like model-based adaptation algorithms (MA), Q-Learning (QL), genetic algorithms (GA), computational learning (CL), and Ant Colony Optimization (ACO). Besides the above three modelling approach groups, there are also other methods developed for strategic bidding, for instance hybrid approaches that combine multiple modelling methods (Li et al., 2011). As each of the modelling methods has specific features, benefits, and limitations of its own, the modelling approach should be chosen based on the purpose of use, the specific characteristics of the problem, and the operating and market environment under study.

Studies discussing smart grid aspects typically emphasize the increasingly important role of DR, DER, and renewables. Especially the challenges related to the increasing penetration of renewables, such as an increase in price fluctuations, are addressed. On the other hand, also the role of DR and controllable DER as potential tools to mitigate price fluctuations and enhance the operation of the market parties and the power system is commonly emphasized. The above aspects are addressed in the majority of the examined studies, but also a variety of other aspects has been brought up. For instance, (You et al., 2009) elaborates on the growing penetration of distributed energy resources (DER) and ongoing liberalization of the electricity markets, which generate new challenges to be answered. (Gordjin and Akkermans, 2007) states that the present stagnation of reserve capacity and emerging price peaks open doors for smart energy services that may provide potential for lower peak prices and lead to a decreasing need for installed peak reserve capacity. The same authors also suggest that the analysis of the future potential of DER requires an analysis of the DER technologies, their characteristics, and the operating environment in which they are used. Further, (Feuerriegel and Neuman, 2013) estimates that the economic potential offered by the demand response for electricity retailers is likely to increase in the future as a result of increasing prices.

To sum up, according to the reviewed publications on smart grid topics, the deregulation itself, the evolution of power markets, and the development of the operating and market environment as a whole are seen to provide new opportunities, but also pose new challenges. Therefore, comprehensive modelling of the retailer's short-term profit optimization problem in the future smart grid environment calls for the development of an appropriate methodology and selection of an appropriate problem modelling approach. They have to capture the specific features of the operating and market environment, enable the management of the emerging risks, and especially, allow the retailer to exploit the profit-making opportunities available. Consequently, both the aspects related to the emerging smart grid environment, and the aspects of the retailer's basic operation such as bidding strategies applied in different markets and hedging established within the long-term planning, have to be considered simultaneously in the methodology development. Hence, there is an abundance of factors that should be considered in order to develop a "perfect" model for the retailer's short-term profit optimization. From a practical point of view, this would complicate the problem modelling excessively, and therefore, the focus has to be kept on the key elements.

Certain common factors can be identified in the studies reviewed on optimal bidding and long-term planning, which are considered among the key modelling aspects. Both categories of studies seem to agree almost universally that the uncertainty related to the future electricity demand and prices, and the risk caused by them, are the main factors to be addressed. However, there is no consensus about the best way to model these uncertainties, or the profit maximization problem itself. Instead, there is a wide array of approaches to the demand and price uncertainty modelling.

In the context of electricity markets, a common and relatively simple approach to model the electricity price and demand is to use historical data. By this approach, the price and demand uncertainties are considered implicitly in the modelling data, and extra modelling complexities can thus be avoided. Historical data are used for example in (Beraldi et al., 2011) in the back-testing analysis, which evaluates the effectiveness of the proposed energy procurement plan based on actual values. Although the application of historical data can be considered a somewhat deterministic approach, it is still quite commonly used in the studies that analyse the economic potential of DER and DR. A practical reason for this is that the detailed modelling of these uncertainties can make the overall optimization problem very complex. Furthermore, to overcome the potential modelling deficiencies such as too case-specific results, for example a sensitivity analysis can be used to test the robustness of the model and to illustrate the impact of the key parameters on the final result. For instance (Gordjin & Akkermans, 2007) has adopted this approach.

Historical data are used in the problem modelling also based on the idea of learning from past experiences such as in (Beraldi et al., 2011; Hajati et al. 2010; Herranz et al. 2012). This combined with the stochastic modelling that takes into account the random nature of electricity price and demand, is generally considered as a convenient modelling approach. Stochastic modelling is especially used in studies on optimal bidding strategies in order to deal with the stochastic nature of the problem. As described in section 3.3.3, although the stochastic modelling approaches enable detailed modelling of price and demand series, they may also result in very complex problems that are very challenging or even virtually impossible to solve by analytic methods, and the numerical solution may lead to too high a computational burden.

The dimensionality and complexity of the retailer's profit optimization problem may easily increase in the future smart grid environment, because the use of DER brings a whole new dimension to the retailer profit optimization. Again, if the use of DER is modelled in a variety of marketplaces along with the present elements of the problem, rather obviously, the problem modelling and solving may become very complicated. Most likely, this is the main reason why studies on optimal bidding strategies typically focus on detailed modelling of price and demand uncertainties (see e.g. Beraldi et al., 2011), whereas DR- and DER-related studies do not address these aspects in such detail. Instead, these studies focus on the modelling of proposed applications, service or business models, and the benefits they can provide. In addition, as (Klaboe and Fosso, 2013) highlights, the reward for tackling the price and consumption modelling complexities may only be a conclusion that does not rely on specific assumptions. From this point of view, it is justified, possibly even necessary, that the smart-grid-related studies simplify price and consumption modelling problems, for instance by using purely historical data. This makes it possible to put more effort into the modelling of DR and DER, and to avoid too complex problems to model and solve. Therefore, it is emphasized that the modelling approach has to be chosen by considering the purpose of use, requirements for the modelling accuracy, and the complexity of the problem.

The adopted modelling assumptions are generally considered among the critical problem modelling aspects in the literature. For instance the uncertainty related to forecasts, the limited availability of data, and the relationships between the price, volume, and competition, are among the most common factors that require the use of modelling assumptions. As (Klaboe & Fosso, 2013) reports, most of the common optimal bidding studies make assumptions concerning the volumes, competition, and prices in the markets. In addition, the studies usually involve assumptions about the applied retail sales pricing models and customers' consumption behaviour. Studies related to the retailer's profit optimization problem in the smart grid environment also typically make some assumptions about considered DER application(s), since the experimental data may be limited or lacking altogether. Depending on the type of DER, different assumptions about the controllability and usability of the capacity are applied. Most commonly, these assumptions are based on historical, statistical, or other research data. In many cases, assumptions have also been made to simplify the analysis, for example by excluding some variables or setting constraints on the operation. This way, even rather complex problems can be simplified so that the problem modelling and solving is easier, or possible. In any case, the applied modelling assumptions, as well as other details of the modelling, should be defined based on the specific characteristics of the market under study, the operating environment, and the problem under consideration.

The studies reviewed in this section also report many interesting results. Studies on optimal bidding strategies such as (Hajati et al., 2011; Herranz et al., 2012), often seem to suggest that by applying the proposed strategy, trades can be adjusted so that higher profits can be obtained. In addition, it is found that a conservative risk attitude corresponds to potentially lower expected profits, while a more risky strategy typically leads to a higher profit, but exposes the market party to higher losses. As (Boomsma et al., 2013) reports, coordinated bidding studies typically also aim at taking the potential arbitrage opportunities between different markets; nevertheless, the gains are generally found to be quite modest. However, they may increase with the penetration of intermittent renewables. According to (Klaboe and Fosso, 2013), significant additional value can also be achieved if the market party is able to defer the bidding decisions in the balancing market until the hour ahead of operation. However, the additional risk of not being dispatched in the balancing market may limit the trading in the balancing market.

Studies on smart grids such as (Feuerriegel & Neuman, 2013; Gordjin & Akkermans, 2007) suggest that the economic potential of DER is likely to increase because of the increasing penetration of renewables and the resulting increase in price variations. Moreover, the new DR-, DSM-, and DER-based applications and services are generally seen as a potential tool to even out these price spikes in the markets and yield significant economic potential for different market parties. (Gordjin & Akkermans, 2007) also suggests that the economic potential of DER can be improved by implementing DER-based applications as a bundle of services, and by trading DER directly in a power exchange market. Finally, (Gordjin and Akkermans, 2007; Feuerriegel and Neuman, 2013) propose technical solutions, concepts, and/or business models that are considered to enable the efficient use of DER in the future smart grid environment.

Based on the above analysis and other literature in the field, it is evident that although the literature on smart grid topics has increased rapidly over the recent years, most studies focus on quite specific problems, and only a very few present comprehensive models for a retailer's short-term profit optimization in the smart grid environment. Most commonly, the studies only introduce the application of some specific type of DER, and/or focus on its use in some particular market or application. Only a few comprehensive models can be found for the market-based use of different types of DER. Furthermore, even these models pay only limited attention to the opportunities of using various types of DER in a variety of marketplaces. Therefore, despite the author's efforts, no such model was found that would consider the use of different DER in a retailer's comprehensive profit optimization in various marketplaces of the short-term markets, including day-ahead, intraday, and reserve markets, and the retailer's balance management. Hence, the novelty of this doctoral dissertation lies in bridging an obvious research gap and developing a comprehensive model for the retailer's short-term profit optimization in the future smart grid environment.

4 Retailer’s short-term profit optimization in the smart grid environment

As it was found in the previous chapter, comprehensive models are lacking for the use of DER in the profit optimization of an electricity retailer in a variety of marketplaces provided by current electricity markets. The development of such a model is not a trivial task as it requires consideration of various aspects related to the planning of the retail business, operation in different electricity markets, and an optimal use of DER. It is virtually impossible to capture all these aspects in detail in one model, and they would easily result in an extensive modelling problem that can be too difficult or time consuming to solve from the practical point of view. Therefore, it is necessary to focus on the key elements of the problem, and adopt an effective but simple enough modelling approach. This chapter summarizes the key elements related to the modelling of an electricity retailer’s short-term profit optimization in the future smart grid environment and presents the proposed modelling approach before the comprehensive model for the use of DER within the retailer’s short-term profit optimization is introduced in Chapter 5.

4.1 Overview of the proposed modelling approach

An electricity retailer’s short-term profit optimization in the smart grid gird environment is a multidimensional problem, which comprises a number of sequential decision-making problems. To model such a problem, a systemic approach to the operation as a whole is required. In addition, the key elements that affect the retailer’s decision-making in different stages of operation have to be identified and included in the model. Therefore, the research problem is approached by analysing elements that affect the retailer’s decision-making and the resulting profits in different stages of operation. The main elements that have a significant impact with respect to the decision-making are identified and included in the model. However, other elements that do not have such an impact can be modelled in a simplified manner, or even excluded from the further problem formulation.

The proposed model has to incorporate not only the retailer’s trading in basic short-term energy markets, but also additional trading opportunities provided by the reserve markets, and profit-making opportunities offered by the use of DER in these marketplaces. In addition, the retailer makes decisions on future trades and the use of DER based on forecasted electricity consumption and prices. It is also pointed out that decisions made in each stage of operation may enable or prevent optimal operation in the future stages. Therefore, the retailer short-term profit optimization has to be modelled in different moments of time and based on uncertain input. This leads easily to very complex modelling problems that are difficult to solve. Moreover, even if an optimal solution for each decision-making problem can be derived, which, however, may be impossible because of the associated electricity price and demand uncertainties, this does not guarantee that a global optimal solution will be found.

Owing to the challenges described above, it is not reasonable to aim at a model with a global optimal solution. Instead, it is justified to take a more practical approach aiming at an optimal solution to each decision-making problem and thereby provide at least an acceptable solution to the global problem. Still, also the systemic approach is simultaneously needed to identify the main risks and profit-making opportunities related to the decisions made in different operation stages. The proposed approach aims to find a solution by solving each decision-making problem separately based on the most accurate data and recent forecasts available, while considering the most significant risks and profit-making opportunities in the future operation.

The focus of the work is on comprehensive formulation of the proposed problem, whereas modelling of all specific details and optimal solution of each sub-problem will receive less attention. This is also supported by the fact that tackling of stochastic modelling complexities, which would probably be required for detailed modelling of all sub-problems, may result in very complex modelling problems, but still, only lead to a conclusion that does not rely on specific assumptions, as highlighted in (Klaboe and Fosso, 2013). Although a deterministic modelling approach may have limited effectiveness (see e.g. Beraldi et al., 2011), it allows compiling an optimal plan under prevailing conditions, and is therefore selected for the problem modelling. In addition, the complexity of the problem and the requirement for fast decision-making needed in changing operating and market conditions support this decision.

To sum up, the proposed model aims to provide a practical decision-making framework that can be used to define an optimal short-term profit optimization plan for an electricity retailer operating in varying market and operating situations. In the model development, the focus is on the use of DER. In addition, detailed consideration of the time dimension of the operation and the key aspects related to the retailer’s risk management and operations in different markets is required. It also has to be borne in mind that the development and implementation of the proposed model are hindered by the limited availability of real-world data and experiences. When data and experiences accumulate, profit optimization can be further developed based on the idea of learning from the past. Therefore, effort is put into the development of a flexible and practical model, which is easy to use and can be adjusted according to the accumulated data, changing operating and market conditions, and based on the retailer’s risk preferences.

The rest of the chapter is organized as follows. First, general modelling assumptions are introduced. Next, a general approach to model the retailer’s cash flows according to the operation horizon is proposed. After that, different aspects of the problem under study are analysed in more detail in order to identify the key elements from the viewpoint of problem modelling. Here, the role of long-term planning is considered first. The main aspects of long-term planning are summarized and analysed in order to identify interactions between the retailer’s long- and short-term operation. Next, application of controllable DER will be introduced, and the associated modelling aspects are examined in more detail. Based on this, an approach for the modelling of DER in the retailer’s short-term operation is proposed. Finally, the risks involved in the retailer’s short-term operation are studied. Various concepts for measuring volume, price, and cash flow risks are introduced and then adopted as risk constraints in the proposed modelling approach. By adopting this approach, the retailer's short-term profit-optimization problem is formulated in Chapter 5.

4.2 Modelling assumptions

The complexity of the retailer's profit optimization problem and the limited availability of data needed for the modelling of the retailer operation and the use of DER require that some modelling assumptions are made. Next, the applied assumptions are introduced in general terms, and more detailed descriptions are given, if necessary, in the context of further problem description.

First, two general assumptions are made. The first one is that the retailer's preceding long-term operation is known and serves as a starting point for the short-term operation. The second one defines that the basic dynamics of DER control actions are known so that the retailer in consideration can accurately enough estimate the DER control capacity available, and the impacts of control actions on the consumption. The above general assumptions are applied to ensure the inputs required for comprehensive problem modelling, as illustrated in Figure 4.1, even if there are not adequate real-world data available for the purpose. Still, the real-world data available are used to model the DER control actions in order to consider the practical aspects of DER control.

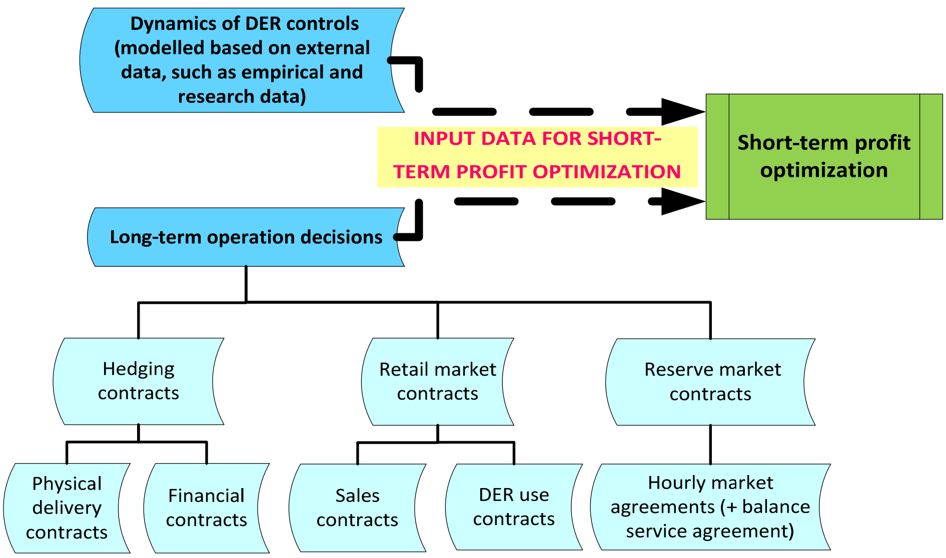

Figure 4.1. Input data from long-term operation and DER control dynamics for the retailer's short-term profit optimization.

Figure 4.1 shows that the retailer makes decisions within the long-term planning regarding the financial and physical hedging contracts, retail market sales and DER use contracts, and hourly reserve market agreements. From the perspective of the problem modelling, these contracts determine the starting point for the retailer’s short-term operation, and enable the operation in different markets and the use of DER in parallel.

The retailer under study has established hedging by making fixed-price physical delivery hedging contracts and financial forward contracts (e.g. DS Futures and Futures) in order to limit the risks. The retailer has set up only conservative physical hedging. Thus, the volume of energy purchased through physical delivery contracts is considerably lower than the retailer’s estimated total consumption. Therefore, the retailer operates mainly as a purchaser in the wholesale market, and only seldom as a seller, for instance to avoid an occurrence of power imbalance or to maximize the profits of the DER use. In addition, it is assumed that the retailer has entered into hourly reserve market agreements. This allows the retailer to freely offer available DER control capacity in the hourly reserve markets at any specific hours. However, trading of the DER capacity through long-term and yearly reserve market agreements, which requires that the capacity is available for the reserve use throughout the year, is not in the scope of this study.

In addition to hedging and hourly reserve market contracts, the retailer has retail sales and DER use contracts. Here, a fixed retail sales price defined by contracts is assumed. In other words, the retailer uses flat tariffs. The DER use contracts give a right for the retailer to control the end-user’s DER within the limits defined by the contract terms, determine the compensations paid by the retailer to the customer, and define other aspects related to the use of end-user-owned DER. In the problem modelling, the limitations set by the contract on the use of DER are addressed by setting the DER control constraints, which prevent the use of DER in a way that would violate the contract terms. It is also considered that the costs from the use of DER do not depend on the purpose of use, but are the same regardless of the marketplace in which DER control actions are applied. Nevertheless, a more detailed analysis of the DER use costs is beyond the scope of this work.

When it comes to the retailer’s own generation, it is assumed that the retailer in question does not have any large-scale production, that is, production units with a nominal power of one megawatt or more. However, the retailer operates in the future smart grid environment and has customers with small-scale production with a nominal power of less than one megawatt. The production of these units is thus included in the current balance model in the consumption balance.

From the perspective of the problem modelling, it is also reasonable to suppose that the infrastructure in the considered smart grid environment allows the retailer to use its controllable DER in various markets cost efficiently. Based on this it is assumed that the DER control actions can be put into practice so that they satisfy the controllability, verification, and other related requirements set by different markets. However, the minimum capacity limits set by markets are considered separately in the problem modelling.

Finally, to overcome the challenges related to the detailed modelling of demand and price uncertainties, which is not among the main objectives of this work, the problem modelling is simplified by assuming that the retailer under study has the required electricity demand and price forecasting applications. These provide the price and consumption forecasts needed for the planning of the short-term operation. It is further assumed that although the performance of these forecasting applications is rather good, the forecasts still include uncertainties. These uncertainties are taken into account in the problem formulation by applying risk constraints, which limit the retailer's risk exposure within acceptable limits. Details of the applied modelling assumptions and other related aspects will be discussed further in the relevant contexts.

4.3 Modelling of cash flows according to the operation horizon

The basic division of the operation (planning) horizon applied to the problem modelling was presented in Figure 3.2. The long-term planning horizon includes establishment of wholesale-side hedging, retail-side sales contracts, and agreements on reserve use, and can thus extend from years to day(s) prior to the moment of delivery. Short-term operation horizon, again, comprises retailer operation in the short-term electricity markets and the use of controllable DER in parallel. Therefore, it stretches from the opening of Elspot trading, which typically takes place on Tuesday one week before the delivery (Nord Pool Spot, 2015e), all the way to market clearing followed by the delivery.

In principle, the retailer's long-term and short-term operations can overlap when the division of planning horizon introduced above is applied. For instance, hedging can be established using day futures even after the Elspot trading for the day in question has started. From a practical point of view, however, it is typically optimal to postpone Elspot trading close to the gate closure, whereas a majority of hedging should be established well in advance in order to manage the associated risks. Therefore, a practical assumption is made that the retailer has accomplished the hedging in full before the start of the short-term operation. Consequently, the long-term planning serves as a fixed starting point for the retailer's short-term operation.

The defined planning horizon division makes it possible to model the retailer's short-term operation independent of the long-term operation. However, it is pointed out that the starting point for the retailer's operation is provided by the decisions made during the preceding long-term operation. In other words, the retailer's long-term operation decisions provide the inputs for the short-term operation. In addition, the long-term operation decisions have a high impact on the retailer's total risk exposure, and may set constraints of their own on the short-term operation. Moreover, there may be some interactions between the retailer's long- and short-term operations, which will be analysed in more detail in the following section. Nevertheless, the cash flows from the retailer operation can be modelled separately in the case of long- and short-term operation. This operation-horizon-based modelling approach, in which the long-term planning serves as a basis for the retailer's short-term operation, is illustrated in Figure 4.2.

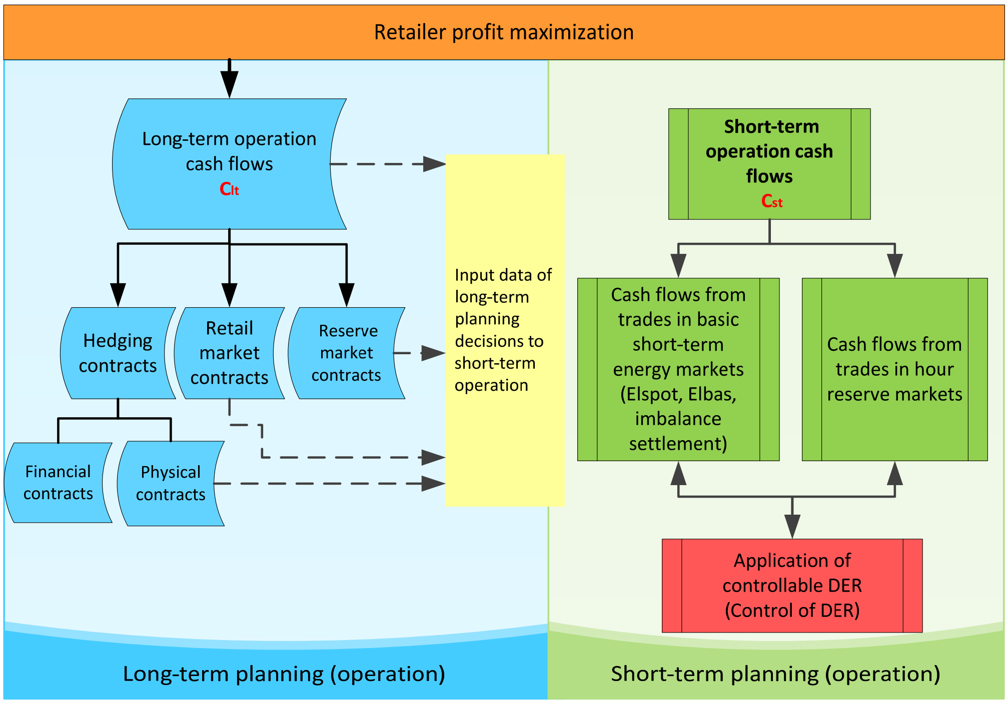

Figure 4.2. Proposed modelling approach. Division of the retailer's operations and the resulting cash flows regarding the long-term and short-term operating intervals and the main elements of long- and short-term operation.

The left side of Figure 4.2, with a blue background, illustrates the main elements of the long-term operation and its role as the basis for the short-term operation. The right side of the figure, with a green background, presents the main elements of the short-term operation. The retailer's cash flows that depend on the long-term planning decisions are from here onwards referred to as long-term operation cash flows and denoted by C_{lt}. Correspondingly, the retailer's cash flows that depend on short-term operation decisions are referred to as short-term operation cash flow and denoted by C_{st}. The input data from long-term planning, which provide a starting point for the short-term operation, are placed in a yellow box in the middle of the figure. The application of controllable DER as an element of the retailer's operation is illustrated by the red box right at the bottom of the figure.

Although categorization of the retailer's cash flows based on the introduced matching principle is rather straightforward in most cases, there are also some exceptions. In addition, it is pointed out that the long-term planning decisions significantly affect the retailer's risks and thereby the planning of the short-term operation. Therefore, the role of the long-term planning from the viewpoint of the short-term problem modelling is analysed in more detail in the following section.

4.4 Consideration of long-term operation aspects

The decisions made by the retailer in the context of long-term operation provide the guidelines on the retailer's short-term operation. Therefore, comprehensive modelling of the retailer's short-term profit optimization problem cannot be accomplished without considering its connections to the long-term operation. In this section, the key aspects of long-term planning from the perspective of the retailer's short-term operation in the smart grid environment are analysed as a basis for the further problem modelling. This is done by first formulating the retailer's long-term operation cash flows in a base case, in which the application of controllable DER to the retailer operation is not yet considered. Based on this, the variables related to the long-term problem and their impacts on the retailer's short-term problem are analysed. For the sake of simplicity, these variables (included in the long-term problem formulation) are referred to as terms in this section.

The retailer's long-term operation cash flows can be formulated by taking into account the established retail sales and wholesale hedging contracts in a base case, in which the application of DER is not yet considered, within an examination interval $t = 1, \dots, T$ as

$$C_{\mathrm{lt}} = \sum_{t=1}^{T} \left(\sum_{n=1}^{N_{\mathrm{re}}} p_{\mathrm{re},n}(t) * E_{\mathrm{re},n}(t) + \sum_{n=1}^{N_{\mathrm{ph}}} p_{\mathrm{ph},n}(t) * E_{\mathrm{ph},n}(t) + \sum_{n=1}^{N_{\mathrm{fi}}} p_{\mathrm{fi},n}(t) * E_{\mathrm{fi},n}(t) \right), \tag{4.1}$$

where

$p_{\mathrm{re},n}$	electricity sales price in a retail contract *n*
$E_{\mathrm{re},n}$	electricity (energy) traded through a retail sales contract *n*
$p_{\mathrm{ph},n}$	electricity price in a physical delivery contract *n*
$E_{\mathrm{ph},n}$	electricity (energy) traded through a physical delivery contract *n*
$p_{\mathrm{fi},n}$	electricity price in a financial contract *n*
$E_{\mathrm{fi},n}$	energy traded through a financial contract *n*
N_{re}	total number of retail contracts
N_{ph}	total number of physical delivery hedging contracts
N_{fi}	total number of financial hedging contracts
t	hour

Because the details of the financial contract settlement are beyond the scope of this work, financial contracts used by the retailer under examination are assumed to be forward contracts such as DS futures and futures. Thus, the price of financial contract (p_{fc}) in Equation (4.1) represents the net value of the contract, which comprises all cost and income components that result in the trading and settlement of the contract.

The terms of Equation (4.1) are next analysed one by one, and then categorized to exogenous parameters and variables from the perspective of the retailer's short-term operation. A term is defined as an exogenous parameter if the retailer cannot affect its value by any means within the short-term operation. Correspondingly, a term is defined as a variable, if the retailer is able to affect the value of the term through its short-term operation. Exogenous parameters affect only the starting point of the short-term operation and the retailer's risk exposure. Hence, these can be excluded from the further short-term problem formulation from the part where the initial values of the short-term problem are considered. Terms that are defined as variables, however, impact on both the long- and short-term operation cash flows. This means that there are interactions between the retailer's long- and short-term operations, which have to be studied in the problem modelling separately in order to model the short-term problem independent of the long-term problem. Table 4.1 summarizes terms of Equation (4.1), presents their categorization into variables and exogenous parameters, and describes their main impacts on the retailer's short-term operation in brief.

Table 4.1. Categorization of the terms of Equation (4.1) applied to the problem modelling and their main impacts on the retailer's short-term operation.

Term of Equation (4.1)	Categorization of term	Central impacts on the retailer's short-term operation and risks
$\boldsymbol{p}_{\mathrm{re}}$ **Retail sales price of electricity**	Exogenous parameter (assuming that retailer uses flat rate retail sales tariffs)	No direct impact on retailer's short-term operation, if electricity is sold at flat tariffs. If dynamic tariffs are applied, impacts of the retail sales price on retailer's sales income and end-users' consumption behaviour (demand-price elasticity) have to be taken into account.
$\boldsymbol{E}_{\mathrm{re}}$ **Electricity (energy) sold through retail sales contract**	Variable	Affects the volume of energy that retailer has to trade or control using DER during short-term operation.
$\boldsymbol{p}_{\mathrm{ph}}$ **Electricity price in physical delivery contract**	Exogenous parameter	No direct impact on retailer's short-term operation, but affects retailer's market price risk exposure.
$\boldsymbol{E}_{\mathrm{ph}}$ **Electricity traded through physical delivery contract**	Exogenous parameter	Impacts the volume of energy that retailer has to trade or control using DER at the time of short-term operation, and through this, on retailer's volume risk. However, does not directly affect the principles of short-term operation.
$\boldsymbol{p}_{\mathrm{fi}}$ **Price of electricity in financial contract**	Exogenous parameter	No direct impact on retailer's short-term operation, but affects retailer's market price risk exposure.
$\boldsymbol{E}_{\mathrm{fi}}$ **Energy traded through financial contract**	Exogenous parameter	No direct impact on retailer's short-term operation, but affects retailer's volume risk exposure.

A retailer cannot affect the price or volume of formerly established financial hedging contracts during the short-term operation, although the settlement of the contracts is made against the system price during the delivery period. Therefore, financial hedging does not directly affect the retailer's short-term operation in terms of physical electricity trading. However, financial hedging affects the retailer's short-term operation through risk exposure. Thus, the terms p_{fi} and E_{fi} are exogenous parameters that affect the retailer's short-term operation mainly only through risk exposure.

Physical and financial hedging established by the retailer affects mainly the retailer's risk exposure at the time of short-term operation. In addition, physical hedging, unlike financial hedging contracts (with the exclusion of EPAD contracts), also provides hedging against an area price risk. Moreover, energy traded through physical contracts (E_{ph}) affects the volume of energy that the retailer has to trade (or control by DER) during the short-term operation. Although physical hedging has thus a significant effect on the retailer's risks and need for future physical electricity procurements, the terms p_{ph} and E_{ph} can be defined as exogenous parameters, because the retailer cannot affect them during the short-term operation.

Specific details of the retail sales pricing have a direct impact on the retailer's risks and sales incomes, but also on the end-users' consumption behaviour. If a retailer sells electricity through flat tariffs, demand response cannot be promoted through pricing incentives. Therefore, in this case, the consumption of the retailer's customers mainly follows the load profiles of the end-user group in question. However, if a retailer applies dynamic pricing models, temporal variations in retail sales prices reflect the end-users' consumption to some extent. Furthermore, also the retailer's sales incomes vary in this case according to the temporal variation of the retailer's sales volumes and prices.

As discussed above, it is assumed that the retailer under study uses flat tariffs, and that the DER use contract between the retailer and the customer defines the terms of DER use. Therefore, the retail sales price of electricity p_{re} is an exogenous parameter from the perspective of the retailer's short-term operation. However, DER control actions taken by the retailer affect the end-users' consumption, that is, the energy sold to the retail customers. Therefore, the term E_{re} is defined as a variable from the perspective of the retailer's short-term operation. The impacts of DER control actions on the retail sales volume also result in changes the retailer's sales incomes compared with the base case, in which no DER control actions are taken. Moreover, the changes in the sales volumes also affect the volume of energy that the retailer has to trade in order to satisfy the customers' demand. Consequently, the impacts of DER control actions on both long- and short-term problem cash flows have to be considered.

In order to model the short-term problem based on a fixed starting point set by the long-term operation, the impacts of the implemented DER control actions on the sales volume and the resulting sales incomes are addressed separately. A change in the retailer's sales incomes as a result of the applied DER control actions can be calculated as

$$C_{\Delta\mathrm{re}}(t) = \left(E_{\mathrm{re,c}}(t) - E_{\mathrm{re,b}}(t)\right) * p_{\mathrm{re}}(t) \tag{4.2}$$

where

$C_{\Delta\mathrm{re}}(t)$	change in the retailer’s sales incomes
$E_{\mathrm{re,b}}(\mathrm{t})$	electricity sold to the retail customers in a base scenario, in which no DER control actions are taken
$E_{\mathrm{re,c}}(\mathrm{t})$	electricity sold to the retail customers in a control scenario, in which the retailer takes DER control actions

Variation in the sales volume as a result of the DER control actions can be estimated as a difference between the retail sales volume (consumption) in the base and control scenarios. The base scenario describes the retailer operation when no DER control actions are taken, whereas the control scenario refers to the same operation scenario, but in this case, the retailer uses controllable DER as part of its short-term profit optimization.

It should be noted that it may not always be possible to accurately verify the impacts of DER control on the retailer’s load profile. This is because the customers’ consumption without applied control actions cannot be known for certain after the control actions have been applied. Still, in general, consumption can be estimated with adequate accuracy, for instance, by comparing the actual load profile after the control actions with the estimated base line consumption, that is, consumption in the base case scenario.

By taking into account the impact of DER control actions on the retailer’s sales incomes, calculated by Equation (4.2), the retailer’s long-term operation cash flows in the smart grid environment can be reformulated based on Equation (4.1) as

$$C_{\mathrm{lt}} = \sum_{t=1}^{T} \Big(\sum_{n=1}^{N_{\mathrm{re}}} p_{\mathrm{re},n}(t) * E_{\mathrm{re},n}(t) + C_{\Delta\mathrm{re},n}(t) + \sum_{n=1}^{N_{\mathrm{ph}}} p_{\mathrm{ph},n}(t) * E_{\mathrm{ph},n}(t) + \sum_{n=1}^{N_{\mathrm{fi}}} p_{\mathrm{fi},n}(t) * E_{\mathrm{fi},n}(t) \Big), \tag{4.3}$$

when variation in the retail sales volumes caused by DER control actions is addressed separately as presented above, the retailer’s short-term operation cash flows can be modelled independent of the long-term operation cash flows. The reason for this is that the long-term operation cash flows are not affected by the retailer’s short-term operation decisions. However, it is necessary to consider the starting point provided by the long-term operation. This is because the retailer’s long-term operation decisions produce inputs to the short-term operation, and thus have an impact on the retailer’s risk exposure at the time of short-term operation. In addition, for instance the volume of energy trades through physical delivery contracts affects the volume of energy that the retailer has to procure in the short-term markets.

4.5 Application of controllable DER

The efficient use of DER requires adequate real-time measurements and practical applications that enable verification (or estimation) of the volume of DER control capacities available and the impacts of planned and implemented control actions on consumption. However, at present, data of measurements that would be required for detailed modelling of DER control actions are limited. Therefore, this section introduces an approach that makes it possible to model a retailer’s DER control actions with an adequate accuracy based on data available such as customer type load profiles, research data of DER control actions, and AMR measurement data. The proposed approach could also be applied to practice, at least in the markets that do not set high requirements on the implementation time and verification of control actions.

4.5.1 Categorization of DER for load modelling

The efficient use of controllable DER in the electricity retailer’s short-term profit optimization requires rigorous modelling of the retailer’s consumption profile, which also includes small-scale production and energy storages. The characteristics of DER may vary significantly in terms of controllability and the impacts of control actions on the retailer’s consumption. An approach to the categorization of DER in a way that allows accurate modelling of various DER is proposed here. However, first, the terminology used in the context of DER modelling is introduced in brief.

The retailer’s DER can comprise various loads, production, and energy storages. Here, the retailer’s DER units refer to the DER belonging to the retailer’s balance responsibility, and which the retailer can control, but which are owned by the end-users. For the sake of simplicity, the term ‘consumption’ is from here onwards used to refer to all energy that is consumed, produced, charged, or discharged as a result of the use of the retailer’s DER units. Consequently, the retailer’s total consumption is the sum of all energy used by DER units that belong to the retailer’s balance responsibility, regardless of the type of the DER units.

The terms ‘active’ and ‘passive energy’ are used to denote energy consumption that originates from the use of different DER units, and which can or cannot be controlled by the retailer. Active energy is modelled in the retailer’s load profile as energy that the retailer can control by increasing or decreasing the consumption of the DER units. Passive energy, which is also referred to as the retailer’s base load (consumption), is modelled in the retailer’s load profile as energy whose volume the retailer cannot affect through its own operation.

The basic principle in the proposed load modelling approach is that the retailer’s consumption is categorized according to its controllability. The upper-level categorization is based on the categorization of the retailer’s consumption into parts that the retailer can and cannot control through the application of DER. Hence, the retailer’s consumption is categorized into active and passive energy, as illustrated in Figure 4.3.

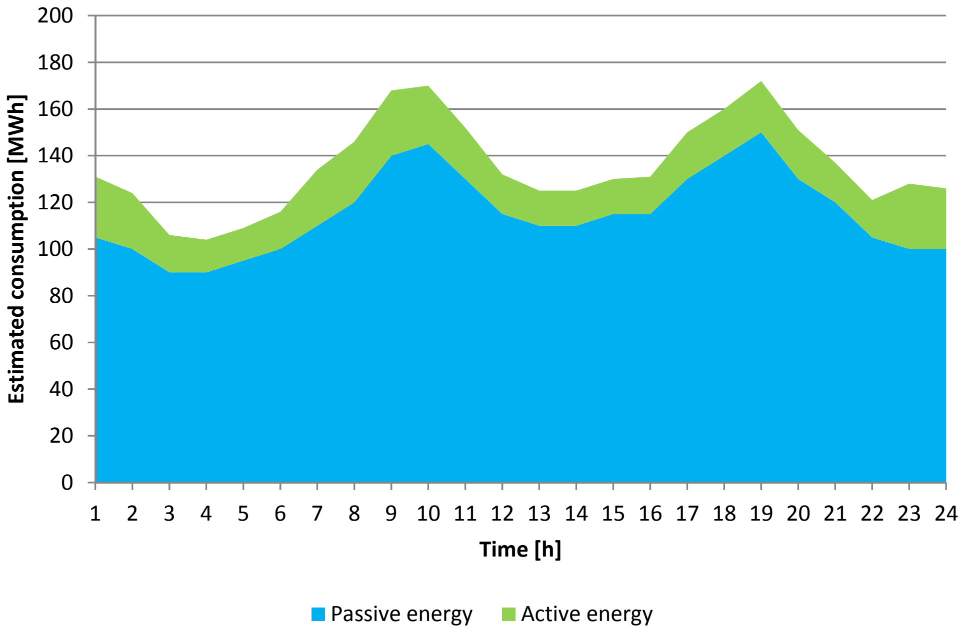

Figure 4.3. Retailer's load profile. Energy consumption that can and cannot be controlled by the retailer is modelled as active and passive energy, respectively.

In the current operating environment, a majority or all of a retailer's typical consumption consists of passive energy, which is represented by the blue background. When transition to the smart grid environment takes place, an increasing proportion of passive energy resources will be converted into active energy resources by control actions. As a result, the proportion of active energy, which is represented by the green background, will increase in the retailer's load profile. Based on the above, an electricity retailer's total energy consumption can be formulated as

$$E_{\mathrm{tot}} = E_{\mathrm{a}} + E_{\mathrm{p}} \tag{4.4}$$

where

E_{tot}	total energy consumption
E_{a}	active energy (consumption)
E_{p}	passive energy (consumption)

In the problem formulation, an increase in the consumption is denoted by positive values, whereas a decrease in consumption is denoted by negative values.

In general, a variety of the retailer's DER can be divided into three main groups; loads, distributed generation, and energy storages. In the future smart grid environment, a majority of DG consists of intermittent renewables, the production of which cannot typically be controlled because of technical or economic reasons. Production of the DG units that cannot be controlled by the retailer reflect on the load profile as passive energy, which decreases the retailer's total consumption. DG can also include a proportion of small-scale hydro, CHP, or other production units that can be controlled by the retailer. This production is seen in the retailer's load profile as active energy that decreases the consumption.

A majority of the retailer's base consumption (load) results from the use of end-users' passive loads, which are seen in the retailer's load profile as passive energy, increasing the consumption. In the smart grid environment, an increasing proportion of the loads are active (controllable) loads. The control of these active loads is typically performed by temporarily disconnecting the loads, which is seen in the retailer's load profile as active energy, decreasing the total consumption. Some loads may also be controlled more flexibly, for instance by scheduling in advance the periods when the loads are on/off.

In the smart grid environment, part of the retailer's consumption originates from the use of energy storages. Because energy storages can be both charged and discharged, the use of an energy storage can be seen in the retailer's load profile either as an increase or a decrease in consumption, respectively. In the proposed approach, energy storages are modelled as loads (charging) and production (discharging), depending on the use of the storage. Although this modelling approach may not be able to cover all aspects related to the control of energy storages in detail, it is accurate and simple enough for the purpose. In general, energy storages can be controlled quite flexibly, and thus, they typically show as active energy in the retailer's load profile. However, energy storages may also be used in specific applications that do not allow the retailer to control the storages. In this case, the use of an energy storage is seen in the retailer's load profile as passive energy.

Considering the optimal use of DER control capacity available, the retailer's consumption has to be categorized in more detail than in terms of active and passive energy. For this purpose, detailed data of the consumption and control dynamics of DER in question are needed. To be exact, the term 'control and consumption dynamics' is used from here onwards to refer to the typical consumption patterns and specific characteristics of DER units. These define how the DER units can be controlled, and how the applied control actions affect the retailer's load profile. Not only the characteristics of DER, but also the end-users' consumption behaviour and preferences set limitations on the use of DER, in other words, affect the consumption and control dynamics of DER.

On the one hand, the accuracy of the load modelling has to be high enough to enable the optimal use of DER. On the other hand, very accurate load modelling may result in complexities and an increasing computational burden, and can thereby hinder the efficient use of DER. Furthermore, from the perspective of consumption forecasting, it may not be convenient to model the rather stochastic consumption of individual DER units; rather, it should be modelled as larger aggregated consumption. When the number of DER units within an aggregated group increases, random variations in consumption (e.g. due to end-users' unforeseen consumption behaviour) will level off. Consequently, the retailer's DER units have to be further divided into smaller groups. However, these groups also have to be large enough in order to avoid challenges associated with the forecasting and modelling of small DER capacities. Therefore, the retailer's active DER units are divided into control groups of appropriate size, each of which comprises DER units that have similar consumption and control dynamics. The retailer's active energy can be formulated according to this categorization as

$$E_{\mathrm{a}} = \sum_{i=1}^{N_i} E_i \tag{4.5}$$

where

E_i active energy consumption of control group *i*
N_i total number of control groups

As each of the control groups consists of DER units that have similar consumption and control dynamics, each control group's consumption follows a specific load pattern. This enables accurate enough forecasting of the control groups' future consumption and modelling of the estimated impacts of planned DER control actions. In addition, DER control constraints for the control groups can be defined according to the typical consumption behaviour and characteristics of the DER units of the control group in question, which enhances the efficient use of the DER control capacity.

In practice, for instance controllable heating, cooling, and ventilation loads could be classified into control groups of their own. However, this categorization may not be accurate enough in all cases. For example, the energy storage capacity of different heating loads varies considerably, which significantly affects the controllability of the loads. Therefore, it is more convenient to apply a more detailed categorization, for example by further dividing the heating loads according to their energy storage capacity. Consequently, a viable categorization for considered modelling purposes can be to divide the heating loads into storage, (partial storage), and direct electric heating control groups.

4.5.2 Basic dynamics of DER control actions

One of the key challenges in the modelling of the retailer's short-term operation in the smart grid environment is to define the dynamics of DER control actions, because data of large-scale actual DER control actions are lacking. This control dynamics describes, for instance, how much a control action decreases or increases the consumption in different times, for how long (duration) the control actions can be applied, and how often control actions can be put into practice (frequency). This section presents the approach adopted for modelling the basic dynamics of DER control actions based on actual measurement and research data. The following sections support this by introducing how general constraints can be defined for DER control actions, and presenting the DER control dynamics in more detail for two example control groups.

An electricity retailer may have a variety of controllable DER, the characteristics of which may differ to a great degree. In general, a DER control action can result in either a permanent change or a time shift in consumption. The control of a load (system) that has only minor or no energy storage capacity such as a lighting load generally results in a permanent decrease in consumption. On the other hand, the control of a load that has a high energy storage capacity such as a storage electric heating load typically results in a time shift of consumption. Consequently, DER control actions can be categorized into actions that have only a primary control effect (e.g. lighting load control) and those which have both primary and secondary effects (e.g. heating load control).

A primary effect of a DER control action is an immediate increase or decrease in the consumption resulting from the control action. A secondary effect of a DER control action, on the other hand, generally results in an opposite change in the consumption compared with a primary effect, which takes place outside the time period of the primary effect. Generally, the secondary effect takes place after the primary effect. However, in some cases such as storage electric heating loads or energy storage control actions, the secondary effect can also be considered to take place before the primary effect. This occurs, in particular, when the retailer or other operator of the DER is able to flexibly allocate the DER use, in other words, schedule the times when an increase or a decrease in consumption takes place. For example, if a load disconnection or discharging of an energy storage results in a 1 MWh decrease in the hour t consumption as a result of a primary effect of the control, the secondary effect of the control can result in a 1 MWh increase in the consumption in hour t+1.

In principle, a control of the DER (system) at one instant results in a secondary effect at a later instant, because the system is recovering from the changes in the system energy balance resulting from the primary effect of the control. Therefore, the secondary effect results in an opposite change in the consumption compared with the primary effect. In terms of an absolute change in the volume energy, the secondary effect typically approximates the primary effect. However, the recovery may also result in a significantly higher or lower (opposite) change in the consumption than the primary effect. The reason for this is that the restoration of the energy balance requires more or less energy as a result of energy losses or external factors such as substitute heating that an end-user has switched on. Consequently, the length of the control action, for instance in the case of heating load control, may also affect the duration and volume of the secondary effect. If the disconnection time is long, or there have been for instance unusually high heat losses at the time of load disconnection, this can result in increased consumption at the time of the secondary effect. Moreover, if the control system does not have energy balance that has to be maintained as in the case of some lighting loads, an applied control may have only the primary effect, because there is no need for the recovery of the energy balance.

The time periods when primary and secondary effects of DER control take place are denoted in the following problem formulation as

$$t = t_{01}, \tag{4.6}$$

$$t' = t_{23}, \tag{4.7}$$

where

t	time when the primary effect of the DER control takes place
t'	time when the secondary effect of the DER control takes place
t_{xy}	time period defined between t_x and t_y
t_0	start time of the DER control primary effect
t_1	end time of the DER control primary effect
t_2	start time of the DER control secondary effect
t_3	end time of the DER control secondary effect

The time when the secondary effect of the DER control takes place in relation to the primary effect of the control can be expressed as

$$t' = t \pm x, \tag{4.8}$$

where x is the time expressed for instance in hours. Alternatively, the time when the secondary effect of the DER control takes place in relation to the primary effect can be expressed through an inequality. For instance, when the secondary effect takes place after the end of the primary effect, the following holds

$$t_2 > t_1. \tag{4.9}$$

A change in the consumption of control group *i* at time *t* as a result of the primary effect of the DER control can be formulated as

$$E_{i,\Delta}(t) = E_{i,\mathrm{c}}(t) - E_{i,\mathrm{b}}(t)\,, \tag{4.10}$$

where

$E_{i,\Delta}(t)$	change in the energy consumption of control group *i* as a result of the primary effect of the DER control at time *t*
$E_{i,\mathrm{c}}(t)$	energy consumption of control group *i* at time *t* in a control case, in which DER control actions are applied
$E_{i,\mathrm{b}}(t)$	energy consumption of control group *i* at time *t* in a base case, in which no DER control actions are applied (baseline consumption)

Correspondingly, the secondary effect of the DER control that takes place at time t' and results from a DER control applied at time *t* (primary effect) can be formulated as

$$E_{i,\Delta}(t') = E_{i,\mathrm{c}}(t') - E_{i,\mathrm{b}}(t')\,, \tag{4.11}$$

where

$E_{i,\Delta}(t')$	change in the energy consumption of control group *i* at time t' as a result of the secondary effect of the DER control, applied at time *t*
$E_{i,\mathrm{c}}(t')$	energy consumption of control group *i* at time t' in a control case where the DER control is applied at time *t*
$E_{i,\mathrm{b}}(t')$	energy consumption of control group *i* at time t' in a base case where no control actions are applied (baseline consumption)

As a result of the DER control action, the energy consumption of control group *i* at time *t*, when the primary effect of the control action takes place changes by the volume $E_{i,\Delta}(\mathrm{t})$. Correspondingly, at time t', when the secondary effect of the applied control action takes place, the energy consumption of control group i changes by the volume $E_{i,\Delta}(t')$. These changes in the consumption can be estimated as a difference between the control group's consumption in a control case and in a base case at specific times. Consumption in the control case refers to the actual verified or estimated consumption after the control actions are taken, whereas the base case consumption, also referred to as baseline consumption, refers to the estimated consumption in a case where no control actions are applied.

The relation between changes in the consumption of control group *i* at the times t' and t, when the secondary and primary effects take place, respectively, can be formulated as

$$E_{i,\Delta}(t') = \beta_i * \left(-E_{i,\Delta}(t)\right), \tag{4.12}$$

where

β_i	payback coefficient of the DER control of control group *i*

The payback coefficient is an experimental coefficient that is used in the problem modelling to describe the relation between changes in the consumption resulting from the primary and secondary effects of a DER control action. The coefficient value $\beta = 1$ indicates that the primary and secondary effects result in changes in the consumption, which have the same absolute volume but opposite directions. The coefficient value $\beta = 0$ indicates that a control action does not result in any secondary effect that would lead to changes in the baseline consumption. The payback coefficient is affected by various factors such as the energy storage capacity and the consumption dynamics of DER. For the sake of simplicity, in the context of further problem modelling it is assumed that the payback coefficients of the example control groups' DER control actions are known.

4.5.3 General constraints of DER control actions

The use of controllable DER in the retailer’s short-term profit optimization is limited by the number of constraints set by the characteristics of the DER, end-users’ preferences, market rules, regulations, and other similar factors. The consumption and controllability between different types of DER can vary significantly, for instance with respect to the permissible maximum length and frequency of control actions. The energy storage capacity of the system, but also other factors such as the end-users’ preferences, have to be considered when defining control constraints for control groups. On the other hand, also the marketplace in which the controllable DER is used sets constraints of its own.

The efficient use of the DER requires that the retailer first defines the consumption and control dynamics, and based on them, the control constraints for the control groups. Thus, the applicability of different DER in different marketplaces can be estimated, which, again, facilitates the planning of optimal control actions. Next, guidelines will be presented on the determination of general constraints for the retailer’s short-term operation in the smart grid environment, and especially for the DER control. However, it is pointed out that the constraints imposed may vary depending on the marketplace in which the retailer operates, which types of DER are controlled, and other similar factors. Therefore, there can also be constraints that have to be defined for each case individually.

First, each retailer operates under load obligation, which requires that the retailer’s consumption matches the volume of energy purchased (or produced) by the retailer in the wholesale markets at each time. Consequently, the following load obligation constraint holds for the retailer operation

$$E_{\mathrm{tot}}(t) = E_{\mathrm{p}}(t) + E_{\mathrm{a}}(t) = \sum E_{\mathrm{proc}}(t) \tag{4.13}$$

where

$\mathrm{E}_{\mathrm{tot}}(t)$	total consumption at time t
$E_{\mathrm{p}}(t)$	passive energy consumption at time *t*
$E_{\mathrm{a}}(t)$	active energy consumption at time *t*
$\sum E_{\mathrm{proc}}(t)$	retailer’s total energy (physical) procurements at time *t*

Equation (4.13) shows that the retailer’s total consumption, which is the sum of passive and active consumption, has to match the sum of physical energy procurements, which are made through long-term physical delivery contracts and trades in the short-term markets. If the retailer uses DER control to adjust its consumption (volume of active energy), the resulting changes in the consumption affect the retailer’s power balance. Therefore, it is important to consider the impacts of the planned DER control actions on the retailer’s consumption as accurately as possible in advance. This way, the retailer can better maintain the power balance by making balancing operations that compensate for the impact of DER control actions on the current power balance.

In general, the use of DER in the retailer's short-term operation is limited by a number of issues. For instance, the control of DER in reserve markets requires that the change resulting from the control actions to the power of the control group can be verified reliably and almost in real time. In practice, the consumption of the control group can be controlled only to a certain limit, which depends on the current consumption of the control group. Thus, the maximum change in the control group power can be formulated as

$$P_{i,\Delta-} \leq P_{i,\Delta} \leq P_{i,\Delta+} \tag{4.14}$$

Correspondingly, the maximum change in the energy consumption of the control group at time *t* is limited as

$$E_{i,\Delta-} \leq E_{i,\Delta} \leq E_{i,\Delta+} \tag{4.15}$$

where

$P_{i,\Delta-}$	maximum decrease in the power of control group *i* as a result of the applied DER control
$E_{i,\Delta-}$	maximum decrease in the energy consumption of control group *i* as a result of the applied DER control
$P_{i,\Delta}$	change in the power of control group *i* as a result of the applied DER control
$E_{i,\Delta}$	change in the energy consumption of control group *i* as a result of the applied DER control
$P_{i,\Delta+}$	maximum increase in the power of control group *i* as a result of the applied DER control
$E_{i,\Delta+}$	maximum increase in the energy consumption of control group *i* as a result of the applied DER control

It may also be necessary to limit the length and frequency of the DER control actions. For instance, in the case of heating load control actions, such a limitation can be applied to make sure that the end-users' comfort is not compromised. For instance, the maximum length of the primary effect of the control action can be limited by the constraint

$$t_{01} \leq t_{01,\max} \tag{4.16}$$

where

t_{01}	duration of the primary effect of the DER control
$t_{01,\max}$	maximum allowed duration of the primary effect of the DER control

The frequency of control actions, in turn, can be limited by the inequality

$$n_i \leq n_{i,\max} \tag{4.17}$$

where

n_i number of DER control actions of control group *i* within the examination interval

$n_{i,\max}$ maximum number of the DER control actions of control group *i* within the examination interval

By using the above general DER control constraints, and considering the need for additional case-specific constraints, the retailer can make sure that the DER control actions can be put into practice without jeopardizing the end-users’ comfort level or compromising the reliability of operation. In addition, constraints set by different marketplaces have to be considered. These market constraints have to be determined based on the current market rules, regulation, and contract terms. Table 2.1 summarizes the market constraints (activation time and minimum size) that set the main limitations on the use of DER in the Finnish power markets. These constraints will be discussed further in Chapter 5.

4.5.4 Modelling of example control groups based on AMR data

This section presents the approach applied to the modelling of the retailer’s DER control actions. The approach is based on the use of actual AMR data, customer type load profile classification, and research data of DER control actions. The proposed approach could also be adopted to practice, at least in the markets such as the Elspot market that do not set very high requirements on the verification of the control actions. In addition, the approach can be useful in the implementation stage of the DER control actions, if real-time measurements and experiences from the application of controllable DER are lacking.

The efficient use of DER and detailed modelling of the application of controllable DER require accurate input data. This means DER unit or control group specific measurement data with a second- or at least minute-level time resolution. In particular, the reserve use of controllable DER calls for real-time measurements or other corresponding verification of control actions. Because such measurement data may not be available, as it is in this case, an alternative modelling approach, which is based on the customer type load profiles and AMR measurement data available, is adopted.

In Finland, customer type load profiles, more information of which is found in (SLY, 1992), are generally used for the classification of electricity end-users based on their typical consumption profiles. A corresponding classification approach is taken here to categorize the retailer’s controllable DER into control groups. More precisely, the consumption of various controllable DER is classified into control groups according to the type load profiles. This makes it possible to model the dynamics of DER control actions using hour-resolution AMR data available, which are generally grouped into measurement databases according to the type load profiles. Before the example control groups are established for the retailer under study, an overview is given of the potential DER applications in Finland.

In Finland, electric heating loads are one of the most prominent load group from the perspective of DER control actions. Electric heating loads can give a considerably high load control potential (capacity), especially in wintertime, and the loads can be controlled without compromising the end-users' comfort. A majority of heating loads can be disconnected at least for one hour, or even for longer time periods, without compromising the end-user's comfort. Still, the maximum allowable length and other constraints applied to the heating load control depend on the type of the heating system, and especially, its energy storage capacity. In addition, for instance the end-users' consumption behaviour and preferences have an influence on the controllability.

From a practical point of view, large-scale and cost-effective implementation of the basic heating load control in Finland can be facilitated by present AMR and AMI infrastructures. These technical characteristics have to enable receiving, implementation, and forwarding of load control commands. The present AMR infrastructure allows for instance the scheduled control of storage electric heating loads in the Elspot market. However, the current AMR systems do not typically enable load control in the reserve markets. For instance long data transfer delays of AMR systems that are based on previous power line communication technologies may not allow the required real-time verification of control actions, although the current data transfer solutions that are based on mobile communication technologies may be able to meet these requirements (Honkapuro et al., 2014; Järventausta et al., 2015; VNa 66/2009; Valtonen et al., 2015).

In any case, the end-users' electric heating loads provide a very potential DER control capacity from the perspective of the retailer's short-term profit optimization. Therefore, two example control groups for the retailer are established of the electric heating loads. The end-users are categorized into control groups according to their heating load consumption and the type load profile classification, and these groups are then used to model the DER control actions of the retailer.

Control group 1, which is from here onwards referred to as CG1, consists of storage electric heating loads. It corresponds to the type load profile number 300, which describes the storage electric heating load customers' consumption. Control group 2 (CG2) consists of direct electric heating loads and water heating loads with a 300 l hot-water tank at the maximum. This control group corresponds to the type load profile 110, which describes the heating load customer consumption profile in question.

The load control capacity of the example control groups is estimated based on the hour-resolution AMR data of the corresponding type load profile customers. To be exact, the load control capacity of the example control group is obtained by extracting the temperature-dependent heating load consumption from the total consumption of the customer group, described by this customer group's AMR data. This can be done, for instance, by applying the methodology introduced in (Mutanen et al., 2011) and (Belonogova et al., 2013). The derived load model represents the control group's heating load consumption, and can be used to indicate the control group's load control capacity available. In other words, by disconnecting all control groups’ loads, the retailer can achieve a decrease in the consumption that corresponds to the current consumption of the control group.

The derived load models can be used directly in historical analyses to model the retailer’s DER control capacity. Correspondingly, the load models can be used as input in the forecasting of the future load control capacity of the control groups. In both cases, it has to be borne in mind that the rather high resolution (one hour) of the AMR data leads to a limited modelling accuracy. Detailed modelling of DER control capacity would require input data with a higher than hour-level time resolution. For instance, the reserve use of DER typically requires the control actions to be implemented and verified fast and accurately. Therefore, also the modelling of DER control actions in the reserve use calls for input data with a second-level time resolution. In order to overcome this and other challenges related to the modelling of DER control actions, certain assumptions are made.

First, it is assumed that the retailer under study can implement DER control actions in the reserve markets in real time and verify them accurately enough by using the measurement and control infrastructure provided by the smart grid environment in question. In addition, it is assumed that the minimum capacity (power) limits set by the reserve markets can be satisfied by allocating some extra capacity for reserve use compared with the estimated consumption. Therefore, a safety margin is set between the power that is offered to the markets and the estimated consumption (control potential) of the hour in question. In the problem modelling it is assumed that when the estimated hourly consumption is at least 30 % higher than the power offered to the reserve market, the control power required for reserve use in the case of accepted offer is available in any case. Correspondingly, by setting adequate safety margins also on other DER control constraints to be applied, it can be guaranteed that the implementation of DER control actions does not compromise the reliability of the operation under any circumstances. The next section presents these DER control dynamics and constraints of the example control groups in more detail.

4.5.5 Control dynamics and constraints of example control groups

The efficient use of DER in the retailer’s short-term profit optimization requires that the electricity retailer has an accurate idea of how the planned or adopted DER control actions affect the consumption. In addition, constraints on the DER control actions have to be defined carefully in order to enable the efficient use of DER without jeopardizing customers’ comfort or compromising the reliability of operation. Therefore, the control dynamics and control constraints for the example control groups are defined in this section. This is accomplished by analysing the load profiles of the example control groups, compiled based on AMR data as presented in the previous section, and using research data of heating load control actions available for instance in (Belonogova et al., 2013; Ericson, 2007; Koponen et al., 2011, Järventausta et al., 2015).

In Finland, storage electric heating loads are generally controlled according to the day–night-time tariff. This means that CG1 loads are switched on around 22:00 when the night-time tariff starts and disconnected when the customer’s daily heating demand is met, but at the latest around 7:00 when the day-time tariff starts. As a result of the high energy storage capacity of the storage electric heating systems, CG1 loads can be controlled flexibly. In principle, shifting of the heating load consumption within hours of a day is only limited by the total heating demand of the customer and the nominal power of the heating system. Based on this, it is assumed that the retailer's hourly consumption does not change as a result of the DER control actions, but only shifts in time as follows

$$E_{\mathrm{CG1},\Delta}(t^{'}) = -E_{CG1,\Delta}(t) \tag{4.18}$$

Constraint (4.18) defines that the primary and secondary effects of control correspond to each other in terms of controlled energy. That is, if the primary effect of control in hour t decreases the retailer's consumption by a volume $-E_{CG1,\Delta}(\mathrm{t})$, the secondary effect of the control increases the consumption by a volume ($E_{\mathrm{CG1},\Delta}(\mathrm{t}')$) in hour t'. It is also assumed that the control actions taken do not affect the hourly heating demand, but only shift it in time. Further, when a heating load is connected, it always consumes the power defined by its nominal power. Therefore, the length of the secondary effect simply equals the duration of the primary effect of the control as

$$t_{01} = t_{23} \tag{4.19}$$

Based on the above, the following holds for the payback factor of the CG1 control actions

$$\beta_{\mathrm{CG1}} = 1 \tag{4.20}$$

From a practical point of view, it is advisable also to assume that the CG1 loads can be shifted only between the hours of a particular day. This also ensures that the daily heating demand of the end-users will be met. Consequently, the following holds for the CG1 control actions

$$\sum_{t'=1}^{24} E_{\mathrm{CG1},\Delta}(t') = -\sum_{t=1}^{24} E_{\mathrm{CG1},\Delta}(t) \tag{4.21}$$

Constraints (4.18)–(4.21) ensure that the end-users' daily heating demand will be met each day regardless of the control actions taken. The duration and number of control actions within a day are also limited by the above constraints, because the retailer plans the control actions at an hour level. Therefore, there is no need to formulate additional constraints, although they could be derived similarly as the constraints for CG2, which are formulated next.

The energy storage capacity of the CG2 direct electric heating and water heating load systems is much lower than that of CG1. Therefore, the consumption of the CG2 heating loads is quite evenly distributed across the day; however, depending on the heating demand, which is mainly defined by the outdoor temperature and the water usage of the end-user. As a result, CG2 loads cannot be controlled as flexibly as CG1 loads. It is estimated based on the research data available and the customers' consumption profile that one-hour continuous disconnection of CG2 can be applied without compromising the end-user’s comfort. Therefore, the maximum continuous disconnection time of one hour is set as the constraint on the CG2 load control as follows

$$t_{01} \leq 1\mathrm{h} \tag{4.22}$$

It should be noted that it may be necessary to limit the maximum continuous disconnection time to be less than one hour in extremely cold weather conditions. For the sake of simplicity, such extreme conditions are not considered here.

Constraint (4.22) defines that the disconnection of CG2 control can be used to postpone the heating load consumption at one hour. After this, the loads are reconnected starting to recover the energy that would have been used normally (without implementation of the load disconnection) at the time disconnection. This secondary effect of control, which is generally referred to as the payback effect of the load control, increases the consumption starting from the reconnection as long as the reference temperature is reached. Similarly as in the case of CG1, it is assumed that an increase in the energy consumption resulting from the payback effect equals the decrease in the energy consumption resulting from the primary effect of the control. This sets the following constraint on the CG2 control actions

$$E_{\mathrm{CG2},\Delta}(t') = -E_{\mathrm{CG2},\Delta}(t) \tag{4.23}$$

Furthermore, the length of the payback effect is also supposed to be equal to the length of the primary effect of the control, similarly as in the case of CG1. Thus, the following holds for the CG2 control actions

$$t_{01} = t_{23} \tag{4.24}$$

As a result of the above, the payback factor of the CG2 control actions is defined as

$$\beta_{\mathrm{CG2}} = 1 \tag{4.25}$$

Based on the above constraints, if CG2 is controlled to apply a load disconnection for a whole delivery hour, the following control action cannot be applied before the secondary effect of the previous control action has ended. Therefore, also the following constraint is applied to the CG2 load control actions

$$t_{0,n+1} \geq t_{3,n} + 1\mathrm{h} \tag{4.26}$$

where

$t_{0,n+1}$ start time of the primary effect of control *n+1*
$t_{3,n}$ end time of the secondary effect of control *n*

Constraint (4.26) defines that after the end of each load disconnection there has to be a one-hour control restraint time, within which a new control action cannot be applied. This constraint is defined by considering that the maximum duration of a load disconnection is limited to one hour. However, if the disconnection time is shorter, also the duration of the payback effect is shorter. In this case, a new control action can be applied earlier without jeopardizing the end-user's comfort. It is pointed out that owing to the above constraints, when a control for CG2 is allocated to hour t, a new control action cannot be implemented either for hour $t + 1$ or hour $t - 1$. The reason for the latter limitation is that if a new control action is allocated to hour $t - 1$, it results in a payback effect for hour t, and thereby prevents the execution of the control action originally planned for hour t.

Finally, the limitations set by the Finnish network regulations are considered. As summarized in (Järventausta et al., 2015), the regulations set two central constraints on the load control actions. The first one is that a continued load disconnection time cannot exceed 1.5 hour, and the second one is that five control actions in a day can be applied at the maximum. Constraint (4.22) ensures that the first requirement is met. The second requirement, again, is taken into account by applying the following constraint

$$n_{\mathrm{CG2,day}} \leq 5 \tag{4.27}$$

where

$n_{\mathrm{CG2,day}}$ number of control actions applied in a day for CG2

Now, the basic constraints for the example control groups CG1 and CG2 are formulated. It is pointed out that the requirements set by different marketplaces on the DER use were not included in the above-formulated constraints. However, these market requirements are listed in Table 2.1, and studied in more detail in the further problem modelling.

4.6 Consideration of electricity demand and price uncertainties

Electricity retailers aim to protect themselves against the majority of risks by establishing hedging within the long-term operation. However, in a long run, hedging decisions have to be planned based on electricity price and consumption forecasts, which involve high uncertainties. Therefore, and as a result of standardized hedging products, it is virtually impossible to establish full hedging, which means that the retailer is exposed to significant risks in the short-term operation. This section presents an approach for the consideration and management of the risks involved in the retailer's short-term operation.

As presented by the literature review in Chapter 3, studies in the field of the electricity retail business present various approaches to model the electricity price and demand uncertainties. A majority of the proposed approaches are based on stochastic modelling, but also deterministic models are commonly used. Stochastic modelling approaches are based on the generation of electricity price and demand scenarios under the assumption of a known probability distribution. The most likely scenario can then be used to represent the expected cash flows, whereas the variation in cash flows between the scenarios reflects the associated risks. Deterministic approaches generally model the problems in specific cases based on the known electricity price and demand data, such as historical data. This generally means that uncertainties related to the electricity price and demand are taken into account implicitly in the modelling data. In addition, scenario or sensitivity analyses can be used to elaborate on the impact of different factors such as realization of a price or volume risk on obtained results.

The risks faced by the retailer within short-term operation depend largely on the hedging decisions made during the preceding long-term operation. Still, market price movements and variations in the estimated electricity consumption define which risks finally materialize and which do not. Therefore, consideration of price and demand uncertainties plays an important role in the retailer's short-term profit optimization. However, modelling of these uncertainties in detail for instance by stochastic modelling is not among the objectives of this work. Instead, a rather practical and deterministic risk modelling approach is taken. It is based on the consideration of electricity price and demand uncertainties through introduction of risk measures that can be used to quantify the present risks. After that, the risk measures are implemented as risk constraints in order to limit the retailer's risk exposure to an acceptable level.

Although the proposed approach may not be able to capture all uncertainties as accurately as some stochastic modelling approaches, it has many advantages. First, the presented model can be adopted to practice by exploiting the variety of existing electricity price and consumption forecasting applications. In addition, the introduced risk constraints can be easily adjusted based on the retailer's risk preferences and exploiting the past experiences. The approach also allows the retailer to operate flexibly in rapidly changing operating and market conditions.

An electricity retailer's risks in the power markets are generally associated with the threat of extra costs. Nevertheless, the market risks faced by the retailers within short-term operation are typically bidirectional. In other words, unforeseen variations in electricity price and consumption can result in either higher or lower profits than expected. Consequently, the retailer's cash flow risk, which is also referred to as cost risk, can be defined as an opportunity or a threat of an increase or a decrease in expected profits (cash flows).

Electricity price and demand uncertainties typically occur in the form of electricity price and consumption forecasting errors. Therefore, the retailer's cash flow (cost) risk in the short-term markets, which results in price and demand forecasting errors, can be formulated as

$$C_{\mathrm{cr}} = p_{\mathrm{er}} * E_{\mathrm{er}} = (p_{\mathrm{act}} - p_{\mathrm{est}}) * (E_{\mathrm{act}} - E_{\mathrm{est}}) \tag{4.28}$$

where

C_{cr} cash flow risk (cost risk)
p_{er} electricity price forecasting error
E_{er} electricity consumption forecasting error
p_{act} actual electricity price
p_{est} estimated electricity price
E_{act} actual electricity consumption
E_{est} estimated electricity consumption

The retailer's cash flow risk is relative to the electricity price and consumption forecast errors, that is, the difference between actual and estimated values. When a retailer plans its electricity procurements based on consumption and price forecasts, errors in consumption forecasts lead to a volume deviation between the retailer's actual consumption and energy procurements. Errors in price forecasts, again, result in a deviation from the retailer's expected cash flows (profits), and may produce misleading signals to the retailer's decision-making.

In addition to the above basic problems, there are also many other aspects that have to be considered when planning the retailer's short-term risk management. First, it is pointed out that the previous hedging decisions have a significant impact on the retailer's risk exposure. In addition, for instance the low performance of the forecasting applications in use and the limited opportunities to manage the identified risks during the short-term operation may pose challenges of their own. In any case, the retailer has to be able to first identify the current risks in order to manage them. Therefore, risk measures that can be used to quantify the risk faced by an electricity retailer within short-term operation will be introduced next. After that, the implementation of these risk measures as risk constraints, which can be used to limit the retailer's risks within an acceptable level, is presented. Finally, the management of the risks involved in the retailer's short-term operation by using the trading opportunities available and using DER is discussed.

4.6.1 Volume risk

Demand uncertainties and the resulting volume deviation risk are basic problems that the retailers face. Hedging established within long-term operation defines the retailer's current volume risks, but options to manage these risks are limited. A price-taker retailer, which does not have market power, cannot affect market prices by its own operation. Therefore, the retailer can manage its risks within short-term operation only by adjusting the power balance between electricity procurements and consumption. Traditionally, the only tool available for this purpose has been trading in the short-term markets. However, in the future smart grid environment, application of DER can also be used for this purpose. Obviously, this improves the retailer's ability to manage the risks. Consequently, the management of volume risk by using controllable DER, in addition to the trading opportunities provided by the short-term markets, is one of the key issues of the retailer's short-term profit optimization in the smart grid environment.

In order to manage the present volume risk, it has to be first quantified by using some reliable measure. Therefore, first, the risk measures will be introduced that can be used to quantify the retailer’s present volume risk, which depends on the hedging decisions made during the long-term operation. As presented in section 3.4.1, the concept of open position is generally used in long-term planning studies to measure the retailer’s volume deviation risk. Here, it is adopted to measure the volume risk faced by the retailer as a result of an incomplete hedging. The open position describes a difference between the retailer’s total hedged electricity procurements and the estimated total consumption as

$$E_{\mathrm{op}} = \left(E_{\mathrm{ph}} + E_{\mathrm{fi}}\right) - E_{\mathrm{tot}} \tag{4.29}$$

where

E_{op}	retailer’s open position
E_{ph}	energy traded (contracted) through physical delivery contracts
E_{fi}	energy traded (contracted) through financial contracts
E_{tot}	retailer’s total consumption (estimated)

It should be noted that the concept of open position takes into account only hedging that is established within the long-term operation interval, but it does not consider possible preceding trades in the short-term markets. Therefore, open position is applicable to the measurement of total volume risks faced by the retailer at the beginning of short-term operation. Open position can be used to quantify the retailer’s volume risk in the context of Elspot trading, and to measure how different DER control actions that are planned prior to the Elspot trades affect the retailer’s volume risk. However, if open position is used to measure the retailer’s risk in later stages of operation such as in the context of Elbas trades, it has to be remembered that open position shows the risk in relation to the established long-term hedging but does not consider the completed Elspot trades. Therefore, also additional volume risk measures are needed, which are able to take into account previous trades made in the short-term market.

The concept of physical open position is applied to the problem modelling to measure the imbalance risk resulting from the retailer’s current physical power imbalance. Physical open position takes account of the retailer’s physical trades, which are made at an area price, but it does not consider financial hedging contracts, which are settled against the system price. Therefore, physical open position also takes into account the area price risk exposure, in other words, shows the position that is not hedged against the area price risk, if separate EPAD hedging is not established when financial hedging instruments are used. The retailer’s current physical open position is calculated as

$$E_{\mathrm{pop}} = \left(E_{\mathrm{ph}} + E_{\mathrm{st}}\right) - E_{\mathrm{tot}} \tag{4.30}$$

where

E_{pop}	physical open position
E_{st}	energy traded in short-term markets

Physical open position describes the difference between the retailer's current physical electricity procurements and the estimated total consumption. The current physical electricity procurements comprise the electricity contracted through physical delivery contracts and electricity traded in the short-term markets so far. Therefore, physical open position indicates the retailer's need for future balancing trades and/or DER control actions in the short-term markets. Consequently, open position can be used to model the retailer's imbalance risk in different stages of short-term operation. For instance, the impact of planned DER control actions in the context of Elbas trades on the retailer's current imbalance risk can be estimated by using physical open position.

When calculating the retailer's volume risks using the above-presented risk measures, the energy purchases (or hedging of purchases) and the estimated total consumption are denoted by positive values, whereas energy sales (or hedging of sales) are denoted by negative values. Therefore, electricity purchases and a decrease in consumption result in a more positive or less negative position, whereas energy sales and an increase in consumption result in a more negative or less positive position.

In some cases it is more convenient to express the value of open position or physical open position as a relative value rather than an absolute value. For instance, if there are considerably high variations in the retailer's consumption within an examination day, the use of a relative volume risk measure can be more illustrative. The relative open position is calculated as

$$E_{\mathrm{op}\%} = \frac{(E_{\mathrm{ph}} + E_{\mathrm{fi}}) - E_{\mathrm{tot}}}{E_{\mathrm{tot}}} * 100 \tag{4.31}$$

and the relative physical open position as

$$E_{pop\%} = \frac{(E_{\mathrm{ph}} + E_{\mathrm{st}}) - E_{\mathrm{tot}}}{E_{\mathrm{tot}}} * 100 \tag{4.32}$$

4.6.2 Profile cost risk

The above volume risk measures, open position and physical open position, can be used to quantify volume deviation risks, but they do not provide information about the monetary value of the risk. The concept of profile cost risk is therefore applied to estimate the value of the risk that arises from volume deviations. The volume deviation can be measured using the above-described volume risk measures, but the cost risk can also be calculated for other volume deviations as long as the risk is valuated appropriately, which means selection of appropriate reference prices in the calculation of the monetary value.

The profile cost risk originates from the retailer's formerly established hedging (trades) that are not optimal considering that a volume deviation in the load profile takes place. Because the retailer's whole position is not hedged, the open position is exposed to a price risk as a result unforeseen market price movements. The profile cost risk describes how the value of the cost risk faced by a retailer varies according to the market price movement and the retailer’s load profile, hour by hour. The profile cost risk is a bidirectional cash flow risk, the materialization of which can result in higher or lower cash flows than expected. In other words, the value of the profile cost risk can indicate either an increase or a decrease in the retailer’s electricity procurement costs and the resulting profits.

The profile cost risk for a volume deviation expressed by open position is calculated as

$$C_{\mathrm{pcr,op}} = E_{\mathrm{op}} * (p_m - p_{\mathrm{ref,hed}}), \tag{4.33}$$

and the profile cost risk for a volume deviation expressed by physical open position as

$$C_{\mathrm{pcr,pop}} = E_{\mathrm{pop}} * (p_m - p_{\mathrm{ref,phy}}), \tag{4.34}$$

with the following notations

$C_{\mathrm{pcr,op}}$	profile costs risk of the open position
$C_{\mathrm{pcr,pop}}$	profile costs risk of the physical open position
p_m	electricity price in a short-term market *m*
$p_{\mathrm{ref,hed}}$	reference price of hedging (average price of prior established hedging)
$p_{\mathrm{ref,phy}}$	reference price of physical trades (average electricity price of prior physical electricity procurements)

The profile cost risk is a product of the volume and the price risk. The volume deviation risk can be represented by using volume risk measures presented in the previous section. The price risk, in turn, can be presented by a price difference between the electricity market price and the reference hedging price. Again, the electricity market price refers to the price at which the volume of energy expressed by the risk measure is traded in the short-term market in question. The reference price of hedging or physical trades, on the other hand, can be represented by the average price of the previously established hedging or physical trades, respectively. Consequently, the value of the profile cost risk depends on the measured volume deviation, the reference price of prior hedging/physical procurements, and electricity price in a market where the balancing trades are made, as illustrated in Table 4.2.

Table 4.2. Impact of open position, market price, and reference price on the retailer's cost risk.

Open position	Market price > reference price	Market price < reference price
Positive	INCOMES from surplus electricity procurements as a result of profitable sell back opportunity/settlement of hedging.	LOSSES from surplus in electricity procurements as a result of unprofitable sell back/settlement of hedging.
Negative	LOSSES from a deficit in electricity procurements as a result of unfavourable high-price purchases in a short-term market.	INCOMES from a deficit in electricity procurements as a result of favourable low-price purchases in a short-term market.

Table 4.2 shows that the direction of open position (positive/negative) and the difference between the market price and the reference price define whether the profile cost risk indicates incomes or losses. The value of the profile cost risk represents the estimated incomes or losses that arise from balancing of the current volume deviation. Consequently, in a hypothetical case, in which the prior hedging or physical procurements are made perfectly so that no volume deviation takes place, the value of the cost risk is zero indicating that the retailer has no cost risk.

The profile cost risk of open position can be used to model the risks associated with the electricity procurement costs in the Elspot market. For instance, by calculating the profile cost risk this way first in a base case (no DER control actions are applied) and then in a control case (optimal DER control actions are applied), the cost risk related to the planned DER control actions can be estimated. The profile cost risk of physical open position can be used to model the risks associated with the retailer's physical electricity procurements, such as balancing operations that are made after the Elspot trades have been completed. Also the risk involved in the planned DER control actions can be evaluated by comparing the profile cost risks of the base and control case scenarios.

4.6.3 Price spike risk

The above-discussed risk concepts can be applied to practice by exploiting different types of electricity price and demand forecasting and modelling applications used by electricity retailers. However, the performance of the present forecasting applications may be quite limited. Especially, forecasting of electricity price spikes is a challenging task, in which few forecasting applications perform efficiently. Still, materialization of the risk of unexpected price spikes can result in high extra costs for the retailer. On the other hand, price variations, and price spikes in particular, can also provide the retailer with remarkable profit-making opportunities. This holds true especially in the future smart grid environment, because the use of controllable DER promotes retailers' opportunities to adjust consumption (power balance) in an optimal direction when a price spike is estimated to take place. However, this requires that the retailer is able to forecast future electricity prices, including the price spikes, with adequate accuracy. Therefore, next, a model is introduced for the consideration of risks and profit-making opportunities related to price spikes by using a hybrid price forecasting model, which is able to forecast not only normal range prices but also price spikes.

A variety of forecasting models that are effective for normal range prices, but which generally disregard price spike events caused by a number of complex factors, have been introduced in the price forecasting literature. However, recently, a few promising models that are efficient also for price spike forecasting have been introduced. A hybrid price forecasting model that predicts not only the day-ahead market prices within the normal range but also price spikes is presented in (Voronin, 2013). The study reports that the proposed hybrid price forecasting model is applicable to the Nordic market and outperforms all competing approaches tested. Therefore, implementation of this hybrid price forecasting model in the context of the retailer’s short-term profit optimization model is considered (Voronin, 2013).

The hybrid forecasting model consists of two modules that separately predict normal prices and price spikes. The price spike module produces the probability of a price spike occurrence, that is, the probability that a price exceeds a specified threshold, which can be fixed or time dependent. Based on the results presented in (Voronin, 2013), the performance of the hybrid price forecasting model is considerably high when it is used in the Elspot market, and especially when it is used to forecast prices only a few hours ahead. In principle, the model can also be applied to other marketplaces such as the balancing market. However, the performance of the model may be rather limited in this case, which makes its use in the context of the retailer’s profit optimization more challenging and risky. Therefore, the hybrid forecasting is applied here only to the forecasting of Elspot price spikes.

The probability of the occurrence of a price spike given by the hybrid price forecasting model is adopted to the retailer’s short-term profit optimization model as an input parameter, which is referred to as the parameter of price spike occurrence and defined as

$$\alpha_{\mathrm{spike}} = P(p_{\mathrm{els}} > p_{\mathrm{th}}) \tag{4.35}$$

where

α_{spike} parameter of price spike occurrence
$P(x)$ probability of event x
p_{els} electricity price in the Elspot market
p_{th} threshold value of the price spike

The probability parameter of price spike occurrence provides an input to the retailer’s profit optimization that supports the retailer’s decision-making with the information whether a price spike is likely to take place or not in the Elspot market. In the problem formulation, the probability parameter of the price spike occurrence is applied as a risk constraint that can be used, similarly as other introduced risk constraints, to determine whether the planned operation (decision) should be made or not, or to select the optimal operation strategy from the alternatives available.

Finally, it is emphasized that the efficient use of the proposed price spike forecasting model requires that the forecasting model is tuned appropriately. For instance, the price spike threshold value has to be defined carefully so that the model correctly classifies the prices as price spikes and normal-range prices. In addition, the retailer has to have an accurate insight into the performance of the model. For this purpose, different performance measures, presented for instance in (Voronin, 2013), can be used. However, more detailed consideration of the tuning of the price forecasting model or performance is beyond the scope of this work.

4.6.4 Implementation of risk measures as risk constraints

The use of the above-introduced risk measures provides the retailer with input data required for optimal planning of the short-term operation. Still, the applied price and demand forecasts always include some uncertainties, which may lead to unfavourable decisions. Therefore, it is essential that the retailer plans its operation so that the associated risks can be managed within acceptable limits. This section presents how the risk measures can be implemented as risk constraints, which can be used simply and efficiently to limit the risks faced by an electricity retailer during the short-term operation.

A risk measure can be implemented as a risk constraint by defining a minimum and maximum limit for the retailer's allowed risk exposure. A risk constraint for a risk measure *RM* can be formulated as follows

$$RM_{\mathrm{min}} \leq RM \leq RM_{\mathrm{max}}, \tag{4.36}$$

where

RM_{min} minimum limit of a risk measure
RM_{max} maximum limit of a risk measure
RM risk measure

The appropriate risk measure *RM* for the specific case can be selected among the following risk measures

E_{op} open position
$E_{\mathrm{op\%}}$ relative open position
E_{pop} physical open position
$E_{\mathrm{pop\%}}$ relative physical open position
$C_{\mathrm{pcr,op}}$ profile cost risk of open position
$C_{\mathrm{pcr,pop}}$ profile cost risk of physical open position
α_{spike} price spike occurrence parameter

A risk measure that is implemented as a constraint can be used to reliably measure the retailer's risk exposure and ensure that the planned operations are acceptable in terms of associated risks. If the value of the applied risk measure is within the defined minimum and maximum limits, a planned operation (decision) is acceptable, and can thus be put into practice. Otherwise, the retailer has to adjust its operation so that the given risk constraints are not violated. Correspondingly, the risk constraints can be used, for instance, to select the optimal decision among the alternatives available. In this case, a set of risk constraints that comprise multiple progressively increasing risk limit values is used. Each alternative decision is represented by a specific risk interval, and the optimal decision is represented by the risk interval within which the calculated value takes place.

In the following problem formulation, an appropriate risk measure, or a combination of risk measures, is applied to the retailer's operation depending on the stage of operation. Thus, the acceptability or superiority of operations and decisions can be estimated. Furthermore, for instance the concept of profile cost risk can also be used to estimate and illustrate the estimated impact of different profit optimization decisions on the retailer's expected cash flows. Moreover, a price spike occurrence parameter can be used, for instance, to indicate the times when a special operation plan could be applied. This way, the retailer can better exploit the profit-making opportunities, or at least manage the risks related to the price spike.

Finally, it is pointed out that the determination of the optimal values of risk constraints can be challenging. For instance, the specific characteristics of the operating and market environment and the retailer's risk preferences should be analysed in this context. This means that the optimal values of risk constraints have to be determined case-specifically. Therefore, the issue is not considered in more detail here.

4.6.5 Summary of short-term risk management

This section summarizes the main aspects of an electricity retailer's short-term risk management in the future smart grid environment. The main focus is on the use of the above-presented risk measures in a company with the application of controllable DER. In addition, the significance of different risks from the perspective of the retailer's short-term operation is addressed in brief.

Although electricity retailers aim to hedge against a majority of market risks in the long term, it is virtually impossible to establish a complete hedge that would eliminate all the retailer's risks. Moreover, it may not even be an economically feasible alternative objective to hedge against all risks, as hedging generally results in extra costs and limits the retailer's profit-making opportunities. Hence, a more feasible strategy is probably to aim at hedging against the most essential risks in a long run, and manage the remaining risk within the short-term operation. This is the case especially in the future smart grid environment, as the application of controllable DER introduces an additional tool for the retailer's short-term risk management.

When a retailer establishes a hedge at the time of long-term planning, the consumption at the time of delivery involves very high uncertainties. This is because the retailer may lose customers for rival retailers or obtain some customers from them. In addition, it is virtually impossible to forecast future consumption accurately even for days, not to mention weeks, months, or even years ahead. As a result, the retailer is almost always exposed to some volume deviation risk. Unforeseen price variations, in turn, expose the retailer's open position to a price risk, which, in the worst case, can result in extensive costs.

In the current operating environment the only feasible tool for a retailer's risk management in the short-term profit optimization is trading in the short-term markets. Thus, the retailer may be forced to make unprofitable trading decisions, even if the possible risks could identified in advance. For instance, if the retailer has a deficit in energy procurements after long-term hedging, but the Elspot, Elbas, and imbalance power prices are high, the retailer has to balance the deficit in any case by purchasing high-price electricity. However, in the future smart grid environment, the application of controllable DER can provide a solution to this problem. By using controllable DER, the retailer may be able to adjust its consumption instead of making unfavorable trades, and thereby manage the identified risks.

The use of controllable DER combined with the introduced risk measures, which can be easily implemented as risk constraints, can be an effective instrument for the retailer's short-term risk management. Open position can be used to measure the volume risks that the retailer faces as a result of incomplete hedging. Physical open position, again, can be used to measure the retailer's imbalance risks. By implementing these risk measures as suitable risk constraints, and planning the trades and the use of controllable DER accordingly, the retailer can efficiently manage the risks associated with volume deviations between the established hedging/electricity procurements and estimated consumption.

It is important to bear in mind that the retailer's total cash flow risk varies hour by hour depending on both the volume and price risks. If there are accurate enough price forecasts available, the concept of profile cost risk can be used to estimate the retailer's total cash flow risk. By defining the hours at which the highest profile cost risk takes place, the retailer can better focus the risk management on the most significant risks. From this perspective, also an ability to indicate price spikes can be particularly useful for the retailer. The use of a hybrid forecasting model, which can forecast both normal-range prices and price spikes, can be a feasible tool for the indication of very high-risk hours in the Elspot market.

The probability of a price spike occurrence produced by the hybrid forecasting model is implemented in the retailer's short-term profit optimization model as a price spike occurrence parameter. By defining appropriate risk constraints for the price spike occurrence parameter, the retailer can easily adjust its operation based on its risk preferences and the probability of the price spike occurrence. For instance, if the price spike occurrence parameter indicates a very probable price spike, the retailer can use the DER control potential available to decrease the consumption at the price spike hour, or shift the consumption from the price spike hour to a lower-price hour. This way, the retailer benefits by purchasing less or selling more electricity at the time of a price spike.

The use of the price spike occurrence parameter, open position, and/or the profile cost risk of the open position as risk measures can be an efficient tool, in particular, for the planning of trades and the use of DER in the Elspot market. After the Elspot trades are made, the main focus should be on the management of an imbalance risk. The concept of physical open position provides a simple and efficient tool for the measurement of the imbalance deviation risk. It expresses the difference between the retailer's current physical electricity procurements and estimated consumption, thus describing the need for balancing operations in terms of a deficit or a surplus in the physical electricity procurements compared with the estimated consumption. Based on the estimated imbalance risk, the retailer can easily plan the required balancing trades or DER control actions and thus manage the imbalance risk.

If reliable price forecasts are available, also the monetary value of the imbalance risk in different hours can be estimated by calculating the profile cost risk of the physical open position. However, it is emphasized that the concept of profile cost risk should be used to measure the risk only if there is a reliable enough price forecast available as input data. Otherwise, it is preferable to use only volume risk measures (open position and physical open position) to estimate the risk exposure, and based on that, manage the risks by minimizing the volume risk. This is because errors in forecasted prices lead to inaccuracies in the calculation of the profile cost risk, which, then, produce incorrect inputs to the short-term risk management. Nevertheless, if the profile cost risk can be calculated based on adequate price forecasts, this ensures more detailed information of the risks, based on which the retailer is better able to manage the risks or even take advantage of more risk-taking profit optimization strategies.

Based on the above, we may state that the application of controllable DER is a very potential tool for the retailer's short-term risk management in the future smart grid environment. Especially, the opportunity to adjust consumption, even if unfavorable market prices make trades in the short-term markets unprofitable, can considerably facilitate the short-term profit optimization. The proposed risk-constrained approach also enables fast and easy validation of the acceptability or superiority of the planned operations. This is especially important in the rapidly changing market and operating conditions. From the practical point of view, it is also important to consider the performance of the forecasting models to be applied. If the performance is high, which indicates reliable and accurate forecasts, the retailer can adopt more risk-taking profit optimization strategies. However, if the forecasts include high uncertainties, more risk-averse profit optimization strategies should be applied. In any case, the option to adjust consumption by using controllable DER, in addition to traditional trades in the short-term markets, can considerably promote the retailer's opportunities for effective short-term risk management and profit optimization in the future smart grid environment.

5 Comprehensive model for the retailer's short-term profit optimization

The retailer's short-term profit optimization in a future smart grid environment is a complex and multi-stage problem, in which the retailer makes decisions regarding the future operation based on the best data and forecasts available. Because electricity price and consumption forecasts include considerably high uncertainties, the retailer faces significant risks that have to be managed rigorously. In addition, the decisions made in each stage of operation set constraints of their own on future operations. Therefore, the profit optimization has to be planned by simultaneously considering various trading opportunities and strategies for the use of DER, taking into account the time dimension of the operation, and risks and profit-making opportunities associated with different decisions. To this end, both a systemic approach to the entire profit optimization process and detailed analyses for different stages of profit optimization are presented in order to derive a comprehensive modelling approach for the retailer's short-term profit optimization in a future smart grid environment.

5.1 Systemic approach

Comprehensive modelling of a retailer's short-term profit optimization calls for understanding of systemic operation, because decisions made in one stage of the operation affect the operation in the following stages. Therefore, before detailed modular modelling of the short-term profit optimization problem, a systemic approach to the problem under study will be presented. As a basis for this, the retailer's short-term operation in the common Nordic electricity markets and in the Finnish hourly reserve markets is presented in this section. Figure 5.1 illustrates the proposed profit optimization approach on a timeline.

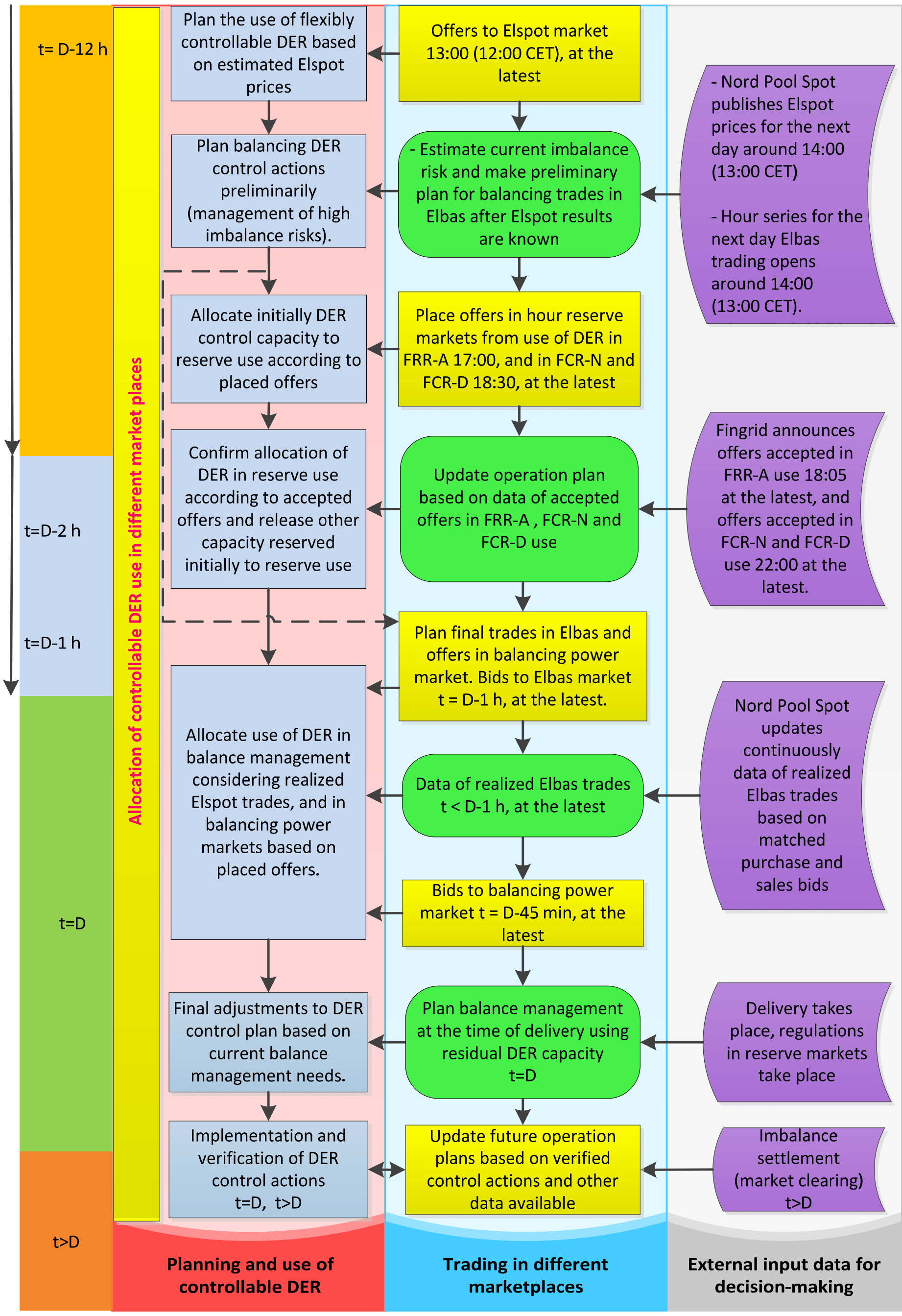

Figure 5.1. Systemic approach to the electricity retailer's short-term profit optimization in a future smart grid environment.

The retailer’s short-term operation in the Nordic power markets and in the Finnish hourly reserve markets is described in Figure 5.1 on a timeline on the left in the figure. The main time limits for the retailer operation are defined by rules, regulations, and contract terms of different marketplaces, all of which will be referred to by the term ‘market rules’ from here onwards. In the market rules, the time periods and instants that set the deadlines for the retailer operation are defined either in relation to the moment of delivery or expressed as a time of day. In addition, both Central European Time (CET) and Eastern European Time (EET) time are used in the definitions, depending on the market rules in question. Central European Time (CET) is one hour behind Eastern European Time (EET), and thus, it has to be borne in mind that a retailer operating in EET makes for instance Elspot trades at the local time t = 13:00 EET at the latest, whereas Nord Pool Spot officially defines the Elspot gate closure to take place at 12:00 CET.

In the context of future modular problem modelling, the time limits for the retailer operation are presented as defined by the market rules, but in the above figure, all day times are presented in EET, for the sake of analogy. In addition, the CET time is presented in brackets after the EET time if the market in question defines the time limits in CET. If a time period or an instance of operation is defined in the market rules in relation to the delivery, the corresponding form of presentation is used also in the problem modelling and in the above figure. In these relative expressions, time t is presented in relation to the moment of delivery, which is denoted by D, as in the case of Figure 2.1 and Figure 3.1. For instance, t = D - X h $\rightarrow$ D + Y h means that the event takes place within the time span that starts X hours prior to and ends Y hours after the delivery. Again, expressions t < D and t >D mean that the event takes place before or after the delivery, respectively.

The right-hand column of Figure 5.1, with a light grey background, shows the key market events that produce the inputs for the retailer’s short-term operation. These inputs include for instance the time limits for operation set by the closing of trading in different marketplaces and announcements of the realized trades and market prices. The light blue column in the middle of the figure shows the retailer’s key operations related to the trading in different marketplaces. The key aspects of the planning and implementation of DER control actions, which are in the focus in the future problem formulation, are presented in the left-hand light red column.

Figure 5.1 shows that the retailer’s short-term operation consists of multiple sequential sub-tasks, the time limits of which are defined by the trading sequence of the markets. Although a detailed strategy for trading and DER use has to be planned separately for each marketplace, also alternative trading strategies should be considered simultaneously for profit-making opportunities that the DER control capacity can provide in different markets. This is because decisions made in one stage of operation may either limit or bring new profit-making opportunities in the following stages of operation. Consequently, the retailer should aim to identify in advance in which market(s) the required energy can be purchased at the lowest price, and in which marketplace the use of DER control capacity yields the highest profits. However, this can be very difficult as a result of the uncertainty of future electricity prices and consumption. In addition, constraints set by different marketplaces, end-users' preferences, and characteristics of the applied DER pose challenges for the short-term profit maximization. Therefore, basically the only feasible solution is to plan the future operations step by step based on the best data and forecasts available, thereby aiming at optimal decisions from the viewpoint of the current and following stages of operation. In addition, as far as this is possible, the most significant risks and profit-making opportunities involved in the operation in later stages of the profit optimization should be taken into account.

Planning of the short-term operation proceeds hour by hour focusing mainly on the current and near-future operation. In addition, the risks related to later operation have to be addressed and managed as soon as possible. Preceding profit optimization decisions may also set their limitations, or open new opportunities for the future operation. Therefore, planning of the hour-level operation requires that various aspects are considered before, at the time, and after the delivery hour in question, as illustrated in Figure 5.2.

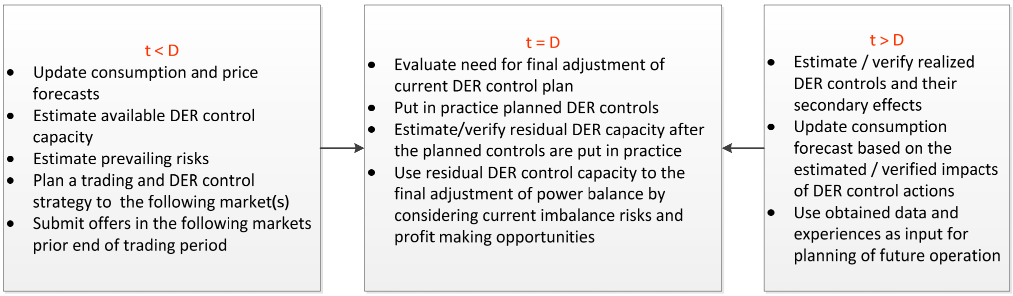

Figure 5.2. Planning of short-term operation by considering the key aspects related to the previous ($t <$ D), current ($t =$ D), and future ($t>$D) operation.

The left-hand, middle, and right-hand boxes of Figure 5.2 present the operations that are related to operation before, at the time, and after each delivery hour, respectively. In practice, the short-term operation has to be planned mainly based on forecasts of future electricity prices and consumption. Therefore, before each delivery hour, the price and consumption forecasts, including forecasts of DER control capacity available, are updated. Based on these data, the retailer plans trades and DER control actions in future markets, as well as submits offers before the end of the trading period.

When all trading decisions have been made and offers to the short-term market are placed, the retailer's options to adjust its operation are basically limited to DER control actions. Therefore, right before the start of the delivery hour, the retailer assesses the need to adjust the current DER control plan. The residual DER control capacity, which has not been allocated to use before, can be used to manage the power balance at the time of delivery. During the delivery hour, the retailer verifies/estimates the impacts of the implemented DER control actions, to the degree it is possible. Based on these data and the recent price and consumption forecasts, the retailer adjusts its power balance by DER control actions in order to minimize the imbalance risk or exploit the profit-making opportunities offered by imbalance power trades. After the delivery hour, the retailer also estimates and verifies the impacts of the completed DER control actions, which have not been verified yet. For instance, there can be secondary effects of DER control actions that can be verified or estimated accurately only after the delivery. Finally, the data and experiences accumulated from the operation are used as the input in the planning of future operations.

5.2 Main stages of short-term profit optimization

This section introduces the main stages of the retailer's short-term profit optimization in a smart grid environment, according to which the problem is formulated in the following sections in more detail. Figure 5.3 presents an overview of the retailer's short-term profit optimization, in which the key decision-making problems are described according to the main stages of operation.

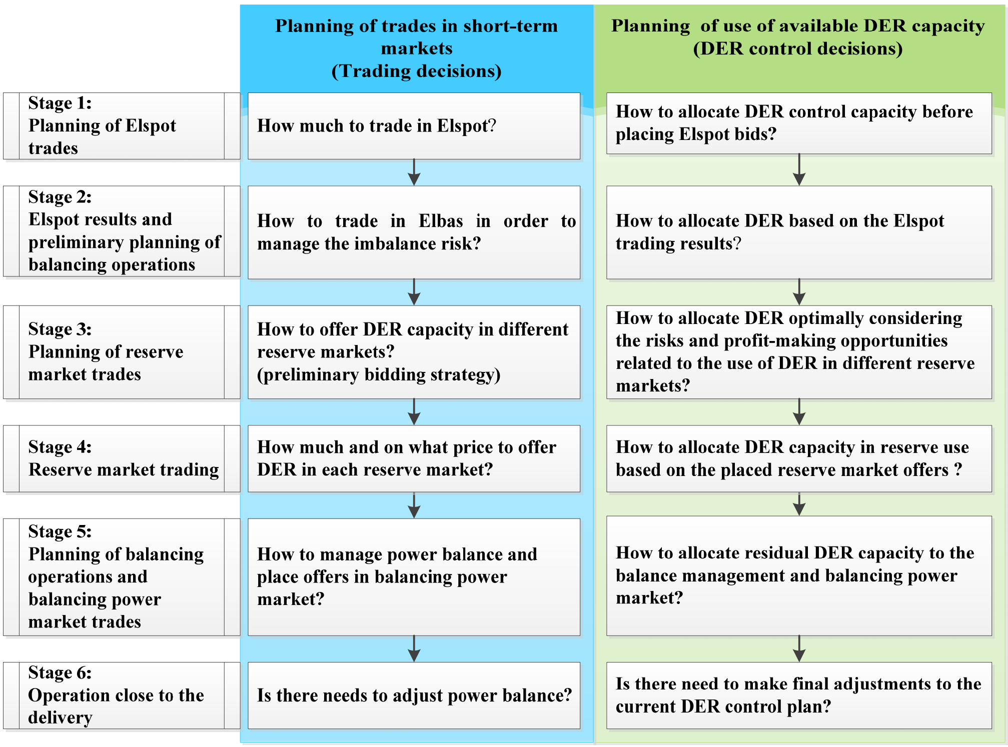

Figure 5.3. Electricity retailer's decision-making framework and the main stages of short-term profit optimization in a future smart grid environment.

Figure 5.3 shows that the retailer's short-term profit optimization problem consists of the following six main stages;

- Stage 1: planning of Elspot trades
- Stage 2: Elspot results and preliminary planning of balancing operations
- Stage 3: planning of reserve market trades
- Stage 4: reserve market trading
- Stage 5: planning of balancing operations and balancing power market trades
- Stage 6: operation close to the delivery

The left-hand column in the middle of Figure 5.3, with the light blue background, illustrates the retailer's decision-making with respect to trading in the short-term markets. The right-hand column, with the light-green background, presents decision-making with respect to the future DER control actions. The retailer decision-making in different operation stages is illustrated by presenting the key questions that describe the decision-making problem at hand. The course of the operation is indicated by arrows, which connect the subsequent stages of operation.

The retailer's short-term operation starts from the planning of Elspot trades. The main aim in the Elspot trading is to procure the energy required to satisfy the estimated consumption. In addition, the retailer aims to allocate DER control actions so that the expected Elspot purchase costs can be minimized. In principle, this means that consumption is shifted from estimated high-price hours to low-price hours, to the degree this is feasible by taking into account the characteristics of the controllable DER. Moreover, if there are clear indications of unusually high or low prices in the future markets, DER control actions can be preliminarily allocated in order to take advantage of them. Finally, by taking account of the allocated DER control actions, the retailer places offers (bids) to the Elspot market before the gate closure of Elspot trading at 12:00 CET.

The next stage, that is, the Elspot results and initial planning of the balancing operations, takes place after 13:00 CET when the Nord Pool Spot has announced realized Elspot prices and trades for the next-day delivery hours. Based on these data and updated consumption (and price) forecasts, the retailer estimates the imbalance risk in different hours and evaluates the need for balancing operations. The focus is on the hours that have a high imbalance risk. In order to manage the imbalance risk within an acceptable level, the retailer draws up an Elbas trading plan. In addition, the retailer makes a preliminary plan for the balancing DER control actions, which aims to ensure that the imbalance risk can be managed even if feasible trading opportunities are not found in Elbas. After this, the retailer follows the Elbas market and aims to make trades in Elbas as soon as feasible trading opportunities emerge. If the retailer is not able to make satisfactory trades in Elbas, the retailer can implement the planned balancing DER control actions at the time of delivery.

Next, in stage 3, the retailer plans trades in hourly reserve markets. First, the retailer estimates the available DER control capacities control group specifically and assesses the applicability of capacities available in different markets. In practice, this means that the retailer analyses in which markets the available residual DER control capacity can be offered, and on which hours of the day. In addition, the retailer considers for instance opportunities to offer capacity sequentially in different marketplaces, the risks associated with the DER control actions, and in particular, their secondary effects. Based on these analyses, the retailer finally plans a sequential bidding plan to take advantage of the sequential operation of the hourly reserve markets.

In stage 4, the retailer makes trades in hour reserve markets. The retailer places offers sequentially to the reserve markets according to the derived reserve market bidding plan. When an offer of the available DER capacity is placed to a market, the offered capacity is allocated initially to the reserve use. After the announcement of accepted offers, the retailer confirms the allocation of DER capacity to the hours in which the placed offers are accepted. In hours at which the offered capacity is not accepted, the retailer releases the initially allocated capacity for a later use. This capacity can thus be offered to the following reserve markets, or used otherwise in later stages of profit optimization. In addition, the retailer updates the preliminary bidding plan based on the announcements of offers accepted in different reserve markets. By applying this operating principle, the retailer offers available DER capacity first to the FRR-A reserve use. The capacity that is not accepted there can be next offered to the FCR-D or FCR-N use. Again, the capacity that is not accepted can be further offered to the Elbas or balancing market, or used in the balance management.

In stage 5, the retailer plans in more detail the balancing operations, which were preliminary planned in stage 2, and trades in the balancing market. If the required balancing trades in Elbas have not been made yet, the retailer aims to make them before the end of the Elbas trading (one hour before the start of the delivery hour). After that, the required balancing operations can be implemented only by means of DER control. As introduced previously, the focus in the planning of the balancing operations is on the management of the imbalance risk, but the retailer can also aim at taking advantage of imbalance power trades. In addition, the retailer plans the use of its residual DER control capacity in the balancing market. When the bids to the market are placed, 45 minutes prior to the start of the delivery hour at the latest, offers to any market cannot be placed for the delivery hour. However, final adjustments to the operation can still be made by DER control actions, as described in the following.

In stage 6, the delivery takes place, and after that, the imbalance settlement is accomplished. During the delivery hour, the retailer's opportunities to adjust its operation are limited to the management of power balance using residual DER control capacity. In addition, some adjustments to the initially allocated DER control actions can be made. However, the binding commitments of DER control actions in reserve use have to be kept unchanged. Implementation of DER control actions takes place at the time of delivery. In addition, the retailer can verify or estimate in more detail the impacts of the DER control actions on consumption at the time of delivery. These and other data of current market and operating conditions are used as the inputs for planning of the final DER control actions. The verification of DER control continues also after the end of the particular delivery hour, if the implemented DER control actions have secondary effects that take place after the delivery. Then, imbalance settlement takes place. In this context, electricity deliveries between the market parties are settled. Finally, the data and accumulated experiences of the operation are used as inputs for the planning of future operation.

To sum up, the retailer's short-term operation comprises six sequential main stages, in which each the retailer aims to make optimal decisions based on the latest available forecasts and data. In order to maximize the total profits, in other words, to derive a global optimal solution to the problem, the whole short-term operation should be planned in detail already in connection with Elspot trading. This is because each decision can set limitations on the decision-making in the following stages of operation. In practice, however, it is impossible to forecast future consumption and market prices so accurately that an optimal solution could be found even for each sub-problem, not to mention a global optimal solution. In addition, it is of importance to manage the risks associated with the demand and price uncertainties while aiming to maximize the profits of the operation. Moreover, it is pointed out that the best solution to the current decision-making problem may not be optimal from the perspective of the global optimal solution.

Owing to the above challenges, instead of aiming at a global optimal solution, the focus is on finding a sub-optimal acceptable solution to the problem. This way, the retailer can manage the risks related to the future electricity price and consumption forecasts when aiming to maximize the profits of the operation. Still, this requires that various constraints, risks, and profit-making opportunities, and other aspects related to the retailer's current and future operation are analysed simultaneously. On the other hand, when a decision is made and put into practice, it obviously cannot be changed later. Therefore, each stage of operation is planned based on previous decisions and considering the key aspects of the future operation. Consequently, the decision-making is accomplished by simultaneously taking a systemic approach and addressing the specific aspects of each operation, and exploiting the best input data available, which here means forecasts of future electricity consumption and prices.

Next, the above complex decision-making problem is modelled in a modular manner. The main focus is on the use of controllable DER within the retailer's short-term profit optimization. In addition, efforts are put into the identification of the most prominent profit optimization strategies and the risks related to different decisions. However, for instance detailed determination of optimal bidding strategies and risk constraints, and consideration of the specific details of consumption and price forecasting are outside the scope of this study.

5.3 Illustration of the problem modelling

The problem modelling is illustrated by using an example retailer that operates in the Finnish electricity markets. The retailer has hedged electricity purchases of 80 MW at the price of 60 €/MWh using financial contracts, and 40 MW at the price of 62 €/MWh using physical delivery contracts. The hedging is established only for risk management, but not for instance to exploit speculative market movements. The retailer sells electricity to the retail customers on flat-rate tariffs at an average retail sales price of 75 €/MWh.

The retailer has controllable DER that can be used actively in the short-term profit optimization. The total DER capacity used by the retailer consists of the two example control groups, namely CG1 and CG2, which were presented in more detail in sections 4.5.4 and 4.5.5. The retailer also operates as a balance responsible party, and thus, the end-users' DER units that the retailer controls are under the retailer's balance responsibility. In other words, the DER control actions applied by the retailer only affect the power balance of the retailer under study.

The retailer operates actively in the Elspot and Elbas markets, and finally, establishes the power balance through imbalance power trades. In addition, the retailer participates in hourly reserve markets aiming to exploit the profit-making opportunities provided by the use of DER in the Frequency Containment Reserve for Normal Operation Reserve (FCR-N), the Frequency Containment Reserve for Disturbances (FCR-D), the Automatic Frequency Restoration Reserve (FRR-A), and the Manual Frequency Restoration Reserve (FRR-M). From here onwards, the above abbreviations are also used to refer to the corresponding hourly markets. Hence, for instance, trading in the FRR-M market means trading in the balancing power market. In addition, assumptions made in section 4.2 and other modelling aspects introduced in Chapter 4 will hold, if not stated otherwise.

It is pointed out that the above-presented contract prices and amounts, risks constraints, and other specific trading volumes and prices used in the following problem formulation are defined mainly for illustrative purposes. Therefore, these values are not optimized in detail. Instead, the efforts are put into the optimization of the retailer operation within these constraints and given initial values. Special efforts are also given to the detailed analyses of the key aspects of the DER use, and their demonstration. This also aims at providing a basic tool that facilitates planning of the optimal DER use. Especially the tables presented in the following problem formulation are designed as a basic tool for the planning of the short-term operation and the use of DER. They are designed to provide an illustrative and compact way to present the retailer's current operation and DER control plan. Similarly, the tables demonstrate the key aspects related to the operation such as impacts of different types of DER control actions on the retailer's load profile, DER capacity available, or expected profits, as far as this is possible considering the scope of the problem. Consequently, the problem formulation also combines detailed analyses and illustrations of DER use and provides basic tools for planning of the DER use.

5.4 Stage 1: Planning of Elspot trades

The retailer's short-term profit optimization starts from the planning of Elbas trades. This stage of operation comprises two central tasks; drawing up a detailed Elspot trading plan and a preliminary short-term operation plan. The main target of the short-term operation plan is to identify the most prominent profit-making opportunities and risks associated with the following stages of operation. This way, the aim is to ensure that the most potential future profit-making opportunities can be exploited and the major risks managed within an acceptable level in time.

A detailed Elspot trading plan comprises a bidding strategy, which is derived by considering the need for trades (electricity procurements) in Elspot and the opportunities to use DER. The upcoming Elspot trades, as well as other operations in later stages, are planned based on recent consumption and price forecasts. The forecasting horizon in the planning Elspot trades is rather long, because the trades for the next day delivery hours have to be made before the gate closure of the Elspot trading at 12:00 CET (13:00 EET). In order to manage the risks associated with electricity price and consumption uncertainties, a risk-averse profit optimization strategy is used.

As a basis for the planning of the next day operation, price and consumption forecasts, including forecasts of the DER control group's control potential (consumption), are updated first. Figure 5.4 illustrates the example retailer's estimated updated load profile, and Appendix A the data based on which the load profile is compiled.

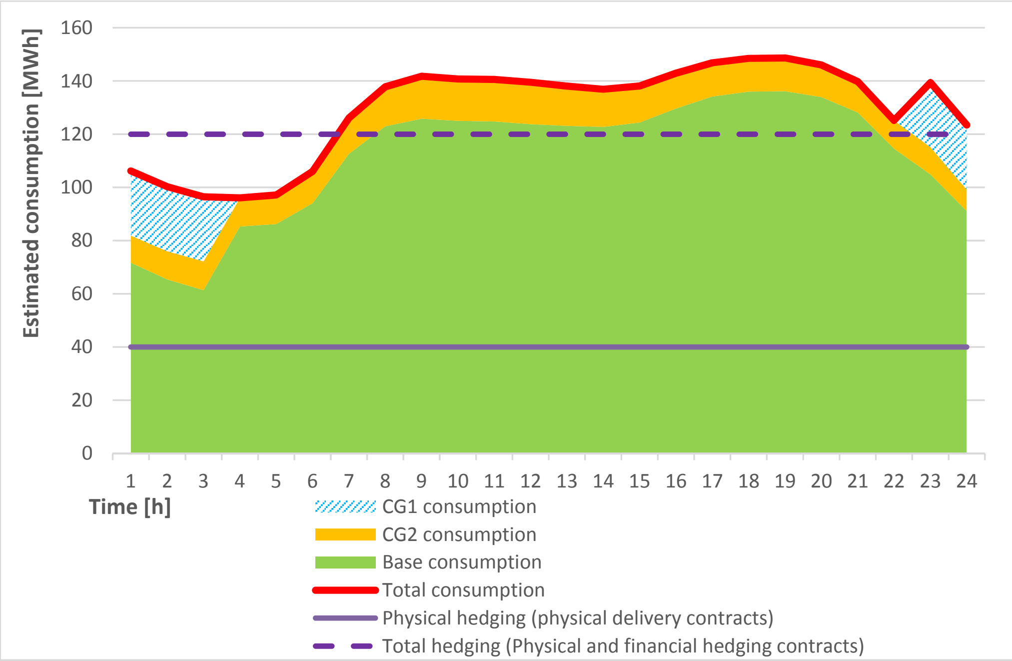

Figure 5.4. Retailer's estimated load profile before Elspot trades.

Figure 5.4 shows that the retailer's base consumption (load), in other words, the passive energy in the load profile, covers a majority of the example retailer's forecasted total consumption. The base consumption is represented by the green area, and the total consumption by the red line. The rest of the retailer's consumption, or the active energy in the load profile, consists of the CG1 consumption indicated by the blue area, and the CG2 consumption represented by the orange area. The hedged electricity purchases, a total of 120 MW, comprise 40 MW of physical delivery contracts and 80 MW of financial contracts. The total level of hedging is depicted by the dashed purple line and the physical hedging by the solid purple one, whereas the area between them represents the financial hedging. This method of presentation is also used in the following load profile figures.

The above figure shows that the retailer has significant variations in estimated consumption, whereas the level of hedging is fixed during the delivery day. Therefore, the retailer is exposed to a considerable profile risk. The retailer's volume risk varies according to the load profile between -29 MWh (hour 19) and +24 MWh (hour 4) expressed by an absolute hourly open position, and -19 % and +25 % expressed by a relative hourly open position, within the examination day.

Based on the updated load profile and the Elspot price forecasts, the retailer defines the operating plan, starting from the determination of a preliminary DER control plan. In principle, there are various alternative DER control strategies that can be applied. However, by taking into account the risks and the profit-making opportunities involved in DER control actions in different marketplaces, some general control principles can be identified, based on which a suitable DER control plan can be defined more easily. These general DER control principles are first summarized below and then discussed in the following section.

- Plan the use of controllable DER based on estimated Elspot prices.
- Aim to exploit profit-making opportunities in reserve markets.
- Minimize the volume risk (or some other specific risk(s))

Analyses of alternative DER control strategies

A rather obvious and a generally feasible strategy in the Elspot trading stage is to plan DER control actions based on estimated Elspot prices. This means that the retailer aims to shift its consumption from the estimated high-price hour to low-price hours. However, in many cases, planning of DER control actions based on Elspot prices can offer a rather modest profit-making potential, as shown for instance in (Järventausta et al., 2015; Valtonen et al., 2015). In addition, price forecasts always include some uncertainties, although for instance (Voronin, 2013) reports that some recent price forecasting applications are able to forecast Elspot prices with a high confidence, including price spikes. Therefore, the decision of the control actions based on the forecasted Elspot prices should be made considering the associated risks and profit-making opportunities. In practice, this means that the price-based strategy should be applied only if the price forecast is reliable enough, and if the expected profits are adequate. The question of what are sufficiently high profits or what is the adequate confidence of the price forecast depend ultimately on the retailer under study.

In general, the DER control can offer an essentially higher profit-making potential in the reserve markets than in the Elspot market (Järventausta et al., 2015; Valtonen et al., 2015). Still, it cannot be known for certain which one is the optimal alternative, because reserve market prices, in particular, can be very difficult to forecast reliably enough. However, for instance, consideration of exceptional operating conditions can, at least in some cases, provide sufficiently reliable indications of high (or low) reserve market prices to justify the allocation of the DER capacity to the reserve use already in the Elspot trading stage. These indications could be obtained for instance at times when there is a shortage of regulating power capacity, which indicates an increase in prices. In addition, for example morning and evening hours, during which consumption is increasing or decreasing at a fast rate, can result in a high demand for regulating capacity, and are therefore potential hours for the reserve use of DER. Moreover, although it is challenging to identify opportune times for the reserve use of DER, the developments in the forecasting applications can introduce new tools for this. In addition, by learning from past experiences and by using an appropriate bidding strategy, the retailer can be able to exploit the most prominent profit-making opportunities in reserve markets more efficiently.

Obviously, if it is possible to identify unusually high (or low) reserve market prices well in advance, these profit-making opportunities should be used by allocating available DER control capacity in the reserve use already in the Elspot trading stage. More importantly, even if there is not clear indication of future reserve prices, it can be a superior strategy to reserve the DER control capacity for later use than to allocate its use based on the estimated Elspot prices. This is particularly the case if the expected profits from Elspot price-based control actions are low, and there is no need to allocate the available control capacity to the risk management purposes.

In some cases, it can be a feasible strategy to allocate DER control actions in order to minimize the current volume risk or some other risk(s). For instance, minimization of the profile risk, which basically means that the retailer aims at a flat consumption profile that matches the established hedging, can be a feasible strategy if the retailer's consumption varies largely within a day. For instance, if the retailer has a high consumption compared with hedging at the times when the estimated prices are high, the DER control actions can be applied to reduce the risk exposure to high prices in some specific hours. Moreover, if the retailer has reliable enough forecasts, it can aim at minimizing the profile cost risk. The basic principle here is of the same kind as in the price-based DER control, but it differs in that the volume of controlled energy can be defined in more detail based on the estimated risk exposure and established hedging.

The retailer can allocate DER control actions to risk management purposes in different stages of operation. For instance, it can be preferable to allocate DER control actions already before Elspot trades, if there are very high volume deviations and/or indicated price spikes that result in substantial risks. On the other hand, after the Elspot trades, the future consumption can usually be forecasted more accurately than before, which makes it easier to plan the optimal management of the volume deviations. Furthermore, based on the realized Elspot trades and prices, the retailer can estimate the optimal DER control strategy more reliably. It is also pointed out that it can be more profitable to make balancing trades in Elbas in order to manage the risks, and use the available DER capacity for instance in the reserve markets.

Based on the above analyses, it is evident that the determination of an optimal DER control strategy in a particular case is not a trivial task, because the risks and profit-making opportunities involved in different DER control strategies depend on various factors. For instance, the volatility of electricity prices, the established hedging, the current load profile, the uncertainty of the future price and consumption forecasts, and the consumption and control dynamics of DER affect the risks and the profit-making opportunities. In addition, for instance the use of DER for the management of the volume deviation risk can limit the retailer's profit-making opportunities in the reserve markets. Consequently, the retailer's risk preferences significantly affect the selection of the DER control strategy. In any case, before the use of DER can be planned in detail, the consumption and control dynamics of DER have to be analysed first in order to address the risks related to the DER control actions and to define the applicability of different DER actions in different markets. Next, the applicability of the example retailer's DER to different types of control is addressed by analysing the consumption and control dynamics of the DER control groups under study.

Applicability of CG1 to different DER control actions

As presented in section 4.5, storage electric heating loads that comprise the CG1 consumption are generally used according to the night-time tariff. Therefore, in a case where no control actions are applied, the consumption currently takes place at night-time hours. The consumption of CG1 depends mainly on the outside temperature. There is a high control potential available in cold winter days, whereas the control potential is modest in summertime, because there is no heating need except for the domestic hot water. As a result of the high energy storage capacity of the storage electric heating loads, CG1 loads can be controlled rather flexibly without compromising the customer's comfort. The CG1 control constraints make it possible to allocate the heating load consumption to any hours of the day, as long as the total heating load consumption and the heating time do not change from the base case. Based on the above, we may state that the control of CG1 loads based on Elspot prices is a rather low-risk and simple strategy to implement but probably provides a rather modest profit-making potential as the consumption currently takes place at typical low-price (night time) hours.

CG1 loads can be used for up-regulation in the reserve markets by disconnecting loads. By taking into account this, the control constraints of CG1, and the requirements set by different reserve markets, the CG1 control capacity can be used in most reserve markets. The control of the CG1 load control actions in the balancing (FRR-M), frequency-controlled disturbance reserve (FCR-D), and automatic frequency regulating reserve (FRR-A) markets are all feasible alternatives. In principle, CG2 loads could also be used for down-regulation, which would enable control actions for instance in the FRC-N use, which sets a requirement on bi-directional control actions. However, this would require that part of CG1 loads are switched on and part off simultaneously. This way, the bi-directional control actions can be put into practice by switching loads on or off when down- or up-regulation is required, respectively. However, the implementation of such bi-directional control actions may be challenging, and the control is less efficient as a double control capacity has to be reserved for the use compared with control actions that are implemented only for up-regulation (load disconnection). Therefore, the use of the CG1 control capacity in the FCR-N is excluded from the analysis, and only the use of CG1 for up-regulation purposes in the reserve markets is considered.

In order to maximize the profits from the reserve use of CG1, its consumption should be allocated to reserve use (up-regulation) so that the highest control potential is available at the times of high-price hours. In addition, it should be borne in mind that the price at which the electricity required to satisfy the CG1 consumption is purchased, for instance in Elspot, affects the profitability of the control. If the reserve market price of an hour is high enough compared with the Elspot price of the hour, the retailer obtains higher profits by the allocation of CG1 loads to the reserve use than by controlling the CG1 loads based on Elspot prices. However, the uncertainty associated with both the Elspot and reserve prices makes the optimal allocation of capacity challenging. In addition, it is pointed out that when energy is purchased in Elspot to cover the CG1 consumption at certain time(s), the implementation of control actions that are not considered in advance result in a power imbalance. Although the retailer is generally compensated for the power imbalances resulting from the reserve use in a particular delivery hour in the imbalance settlement, imbalances resulting from the secondary effects of control actions outside the delivery hour are not compensated for. Therefore, the secondary effects of control actions can expose the retailer to a significant imbalance risk. Consequently, although the allocation of the CG1 capacity to the reserve use may offer a significant profit-making potential, it can also expose the retailer to high risks.

Applicability of CG2 to different DER control actions

The CG2 consumption and control dynamics differ markedly from the CG1 control dynamics, mainly because of the lower energy storage capacity of the CG2 heating loads. This and especially the payback effect (secondary effect) of CG2 control actions pose serious challenges to the planning of optimal control actions. The payback effect takes place right after the end of the primary effect of the control and results in an increase in the retailer’s consumption. Therefore, allocation of CG2 control actions requires that the retailer considers these impacts in advance, or makes balancing trades afterwards in order to maintain the power balance. In the worst case, incorrect timing of control actions can result in substantial extra costs; this is explained by the fact that the balancing energy, which is required to cover the increase in consumption at the time of the payback effect, has to be purchased at a higher price than the energy is sold (not purchased) in the markets at the time of the primary control. Therefore, special attention has to be paid to the payback effect of the control in the allocation of the CG2 control capacity.

The CG2 consumption depends mainly on the outside temperature and the end-users' water usage. Therefore, the highest control potential is available in cold winter days, whereas only modest, if any, control potential is available in the summertime. As a result of the low energy storage capacity, the consumption of CG2 is typically rather evenly distributed across the day, however, depending on the variations in the outside temperature and water usage. As presented in section 4.5.5, according to the control constraints of CG2, five one-hour control actions at the maximum can be performed in a day. In addition, after each control action there is one hour of period where a new control cannot be implement. This time is later on referred to as control restraint time.

By taking account of the control and consumption dynamics of CG2 and uncertainties involved in the future market prices, planning of CG2 control actions based on the estimated reserve market prices is not a generally feasible strategy in the Elspot trading stage. The option of making load disconnections only limitedly, together with unforeseen price variations, exposes the retailer to high risks because of the payback effect of the disconnections. For the same reason, also the control of CG2 loads based on estimated Elspot prices is a feasible strategy, only if adequate profit-making potential for control is found and the Elspot price forecast is reliable enough. The profit-making potential is found when high enough price differences between consecutive hours take place. More precisely, profits are obtained from the control actions if the consumption can be decreased by disconnecting the load in the high-price hour t, and the increase in the consumption as a result of the payback effect takes place in the low-price hour t+1.

Consequently, the implementation of CG2 control actions has to be planned carefully. For instance, a price spike in an individual hour can provide an adequate incentive for the implementation of the control actions based on Elspot prices. However, if the expected profits of a control action are low compared with the associated risks, the implementation of control actions is not recommendable. Instead, it is preferable to preserve the available control capacity, and allocate it to the later stages of operation, if adequate profit-making potential emerges for instance in the reserve markets. Still, it has to be borne in mind that the implementation of CG2 control actions in the reserve markets involves a considerably high risk as a result of the payback effect of the control. Nevertheless, the CG2 control capacity, similarly as CG1, can be used in the reserve market for up-regulation (load disconnection). In addition, the risks associated with the payback effect of the control can be managed, at least to some extent, by planning the offers in the reserve market in detail, as will be discussed later.

5.4.1 Allocation of DER control actions

It is essential to consider the uncertainty of future price forecasts, if they are used as the input data for the planning of DER control actions. Here, it is assumed that the retailer has a quite precise anticipation of the future Elspot prices, whereas the future reserve market prices are mainly unpredictable. Consequently, the risks are high related to the allocation of DER control actions in the Elspot trading stage in the reserve markets. In addition, minimization of the volume risk is regarded as an unfavourable alternative, except in the case that the volume risk is exceptionally high in some hour, because it can reduce the future profit-making opportunities. Thus, the most feasible alternative here is to plan the DER control actions based on the estimated Elspot prices and considering the estimated risks and possible later (emerging) profit-making opportunities for the DER use.

Planning of the DER control actions according to the estimated Elspot prices is based on the idea that the consumption is allocated to the hours where the energy consumed can be purchased at the lowest price. The objective to minimize the electricity purchase costs during the examination day by allocating the DER control capacity of control group *i* in the Elspot trading is formulated as

$$\text{Min} \sum_{t=0}^{24} \left(p_{\text{els}}(t) * E_i(t) \right), \tag{5.1}$$

where

$p_{\text{els}}(t)$ Elspot price in hour t
$E_i(t)$ estimated energy consumption of control group *i* in hour *t*

Minimization of the Elspot purchase costs in the Elspot trading stage can be regarded as an optimal strategy in this case, because the retail sales price is fixed. In addition, the control group's consumption does not change (β=1), but only shifts in time as defined by the consumption and control dynamics of the control groups (see section 4.5.5).

The estimated changes in the retailer's cash flows, in other words, savings in the Elspot purchase costs, for a single DER control action can be formulated as

$$C_\Delta(t, t') = p_{\text{els}}(t) * E_{i,\Delta}(t) + p_{\text{els}}(t') * E_{i,\Delta}(t') \tag{5.2}$$

where

$C_\Delta(t, t')$ change in the retailer's cash flows in hours t and t'
$E_{i,\Delta}(t)$ change in the energy consumption of control group *i* as a result of the primary effect of the DER control at time *t*
$E_{i,\Delta}(t')$ change in the energy consumption of control group *i* at time t' as a result of the secondary effect of the DER control, applied at time *t*

If time-variable retail sales prices are to be applied instead of fixed prices, the objective to maximize the profits during the examination day by allocation of the DER control capacity of control group *i* in the Elspot trading stage can be formulated as

$$\text{Max} \sum_{t=0}^{24} \left(\left(p_{\text{re}}(t) - p_{\text{els}}(t) \right) * E_i(t) \right), \tag{5.3}$$

In this case, DER control actions are planned so that the profit margin, that is, the difference between the retail sales price and the Elspot purchase price, is maximized. The estimated profits of a single DER control action when time-variable retail sales prices are used can be formulated as

$$C_{\Delta}(t,t') = \left(p_{\mathrm{re}}(t) - p_{\mathrm{els}}(t)\right) * E_{i,\Delta}(t) + \left(p_{\mathrm{re}}(t') - p_{\mathrm{els}}(t')\right) * E_{i,\Delta}(t') \tag{5.4}$$

CG1 loads can be controlled flexibly, and also in later stages of operation, even if the consumption is first allocated based on the estimated Elspot prices. Therefore, the example retailer aims to shift the CG1 consumption to the hours where the lowest Elspot prices of the day take place, according to the cost minimization objective of Equation (5.1). The objective to minimize the costs is met by shifting the CG1 consumption from the hours that currently have consumption and the estimated price is higher to the hours that currently have no CG1 consumption, and the estimated price is lower. This allocation is repeated hour by hour as long as all CG1 consumption takes place at hours with the lowest prices of the day. Obviously, the control actions have to be allocated within the CG1 control constraints, presented by Equations (4.18)–(4.21). In addition, the risk constraints that are presented later cannot be violated either.

CG2 loads cannot be controlled as flexibly as CG1 loads, because the payback effect of the control action takes place right after the primary effect of the action, and thus, easily hinders allocation of new control actions and calls for balancing trades. Consequently, control actions planned in the Elspot trading stage can limit later profit-making opportunities, and combined with inaccuracies in price forecasts, result in a considerable risk for the retailer. Therefore, it is preferable to allocate CG2 control actions based on the estimated Elspot prices only if high enough profits are expected, which presumably compensates for the associated risks. Therefore, the retailer's risk preferences, uncertainty of price forecasts, expected market price fluctuations, and other factors that affect the expected profits and risks of allocated control actions should be considered when defining adequate expected profits.

Here, it is approximated that the recent and future average price variations between consecutive hours are less than 10 €/MWh in the markets under study. Based on this, it can be estimated that the average profit-making potential for a single CG2 control action should be more than 10 €/MWh in order to take advantage of the best profit-making opportunities and to compensate for the risks. Otherwise, it is preferable to preserve the control capacity for a later use. The higher is the limit set for the adequate expected profits, the lower are the risk associated with price variations and mistiming of control actions. By taking the above into account, it is concluded that the sufficient expected profit for the risk-averse retailer is 20 €/MWh from a single CG2 control action. Based on this, the following additional control constraint is set on the CG2 control actions in the Elspot trading stage

$$p_{\mathrm{els}}(t) - p_{\mathrm{els}}(t+1) \geq 20\ €/\mathrm{MWh} \tag{5.5}$$

CG2 control actions are allocated in the Elspot trading stage only if the forecasted price difference between consecutive hours is at least 20 €/MWh. Furthermore, the control actions have to be implemented within the control constraints of CG2, determined by

Equations (4.22)–(4.27). Moreover, the applied risk constraints, which are introduced next, cannot be violated either. Before this, it is still pointed out that the constraint of Equation (5.5) and the following risk constraint are not optimized in detail here, but defined for illustrative purposes only. In practice, they should be optimized in more detail considering the retailer's risk preferences, profit target, market price movements, and other similar factors.

First, the risk constraint for the retailer's short-term operation is applied to limit the associated risks, or to benefit from electricity prices spikes, and is formulated as

$$\alpha_{\mathrm{spike}} \geq 100 \text{ €/MWh} \tag{5.6}$$

The applied price spike constraint determines that when the forecasted Elspot price is higher than 100 €/MWh, it is classified as a price spike. Here, the value of the price spike risk constraint is approximated roughly, similarly as constraint (5.5), based on the estimated future prices and recent historic prices. In practice, the confidence and accuracy of the forecasts can be measured in more detail for instance by applying performance measures introduced in (Voronin, 2013), and used as an input for the determination of the optimal price spike constraint. In addition, the retailer's risk preferences, and the volatility of prices in general, should be considered when defining a convenient price spike constraint.

In the case of a classified price spike, the retailer makes more detailed analyses of the associated risks and the profit-making potential, and adjusts its operation accordingly. If the price forecast is found reliable, as it is assumed in this case, the retailer aims to take advantage of the spike by controlling the DER based on the estimated Elspot prices. However, should the confidence of the price forecast be low, a preferable strategy would be to aim at minimizing the volume risk at the time of the price spike.

The second risk constraint is applied to limit the retailer's volume risk exposure, which is measured here by using a relative open position, and is expressed as

$$-30\ \% \leq \mathrm{E}_{\mathrm{op\%}}(\mathrm{t}) \leq 30\ \% \tag{5.7}$$

where

$\mathrm{E}_{\mathrm{op\%}}(\mathrm{t})$ relative open position in hour *t*

The above constraint defines that the retailer's relative open position cannot deviate by more than $\pm$ 30 % in any hour of the day before the Elspot trades are made. If this does not hold, the retailer allocates DER control actions before the Elspot trades, as far as this is possible, to manage the open position within these risk limits. This rather loose limit for the allowed volume risk is defined by considering the retailer's load profile, future trading opportunities, and the risk preferences of the retailer. The allowed deviation of the open position has to be high enough, because the retailer's consumption varies within the delivery day, whereas the level of hedging is fixed. In addition, all trading opportunities in the short-term markets are still open. Even if price risks materialize as a result of inaccurate Elspot price forecasts, the retailer can still make balancing trades or use the DER available to manage the imbalance risk after the Elspot trades. On the other hand, risk constraints have to limit the realization of too high a volume risk. The retailer's consumption varies from 97 to 149 MWh/h within the day, and the total hedging level is 120 MW. Based on this, it is approximated that the set volume risk constraint prevents operations (e.g. load control) that would result in too high a risk for the (risk-averse) retailer, but the constraint still does not limit normal operation.

The actual impacts of the planned DER control actions on the retailer's cash flows (profits) are known only after the allocated DER control actions are implemented in practice. However, the impacts of the control actions can be estimated approximately in advance based on the forecasted prices and consumptions to support the retailer's decision-making. The impacts of the DER control actions of control group *i* in hour *t* on the retailer's cash flows (profits) can be calculated as

$$C_{i,\Delta}(t) = E_{i,\Delta}(t) * \left(p_{\mathrm{re}}(t) - p_{\mathrm{els}}(t)\right), \tag{5.8}$$

If the control results in secondary effects, their impact on the retailer's cash flows in hour t' can be calculated as

$$C_{i,\Delta}(t') = E_{i,\Delta}(t') * \left(p_{\mathrm{re}}(t') - p_{\mathrm{els}}(t')\right). \tag{5.9}$$

The total change in the retailer's cash flows resulting from the DER control actions of control group *i* applied in day *d* is thus calculated as

$$C_{i,\Delta}(d) = \sum_{t=1}^{24} C_{i,\Delta}(t) + \sum_{t'=1}^{24} C_{i,\Delta}(t'). \tag{5.10}$$

Although the above equations are formulated for the calculation of cash flows produced by DER control actions in the Elspot market, they can also be used in other similar energy markets by considering the price of the market in question in the calculations.

The above-planned DER control actions affect the retailer's consumption and thus also the risks and cash flows. Figure 5.5 presents the retailer's estimated load profile after the allocated DER control actions, and Table 5.1 presents in more detail the estimated impacts on consumption, risks, and expected profits. Data used to compile the load profile in Figure 5.5 are presented in Appendix B.

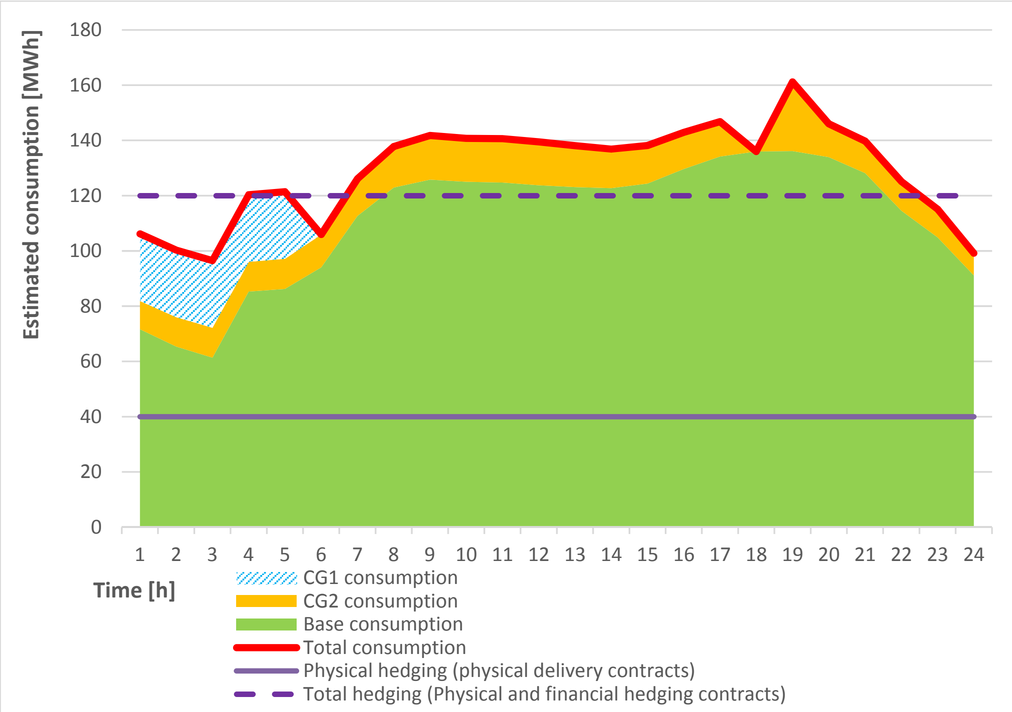

Figure 5.5. Retailer's estimated load profile after the DER control actions are initially planned based on Elspot prices.

Table 5.1. Estimated impacts of planned DER control actions on retailer's consumption, risks, and expected profits.

		Before allocation of DER control actions		After allocation of DER control actions				
Hour	**Elspot price forecast [€]**	***CG1 cons. [MWH]***	**CG2 cons. [MWH]**	***CG1 cons. [MWh]***	**CG2 cons. [MWh]**	**Relative hourly Open position [%]**	**Profile cost risk of open position [€]**	**Expected changes in profits [€]**
1	31	*24.3*	10.2	*24.3*	10.2	13.0	-414.7	0.0
2	31	*24.3*	10.6	*24.3*	10.6	19.7	-591.3	0.0
3	32	*24.3*	10.9	*24.3*	10.9	24.4	-682.1	0.0
4	34	*0.0*	10.8	*24.3* *(24.3)*	10.8	-0.3	9.5 (655.6)	995.5
5	35	*0.0*	10.9	*24.3* *(24.3)*	10.9	-1.2	37.3 (631.3)	971.2
6	45	*0.0*	11.9	*0.0*	11.9	13.3	-224.8	0.0
7	60	*0.0*	13.5	*0.0*	13.5	-4.8	6.1	0.0
8	70	*0.0*	14.9	*0.0*	14.9	-12.9	-160.3	0.0
9	67	*0.0*	16.0	*0.0*	16.0	-15.4	-130.7	0.0
10	65	*0.0*	15.7	*0.0*	15.7	-14.7	-83.0	0.0
11	62	*0.0*	15.9	*0.0*	15.9	-14.7	-20.6	0.0
12	56	*0.0*	15.8	*0.0*	15.8	-14.0	97.5	0.0
13	56	*0.0*	15.0	*0.0*	15.0	-13.1	90.5	0.0
14	70	*0.0*	14.2	*0.0*	14.2	-12.3	-152.0	0.0
15	80	*0.0*	13.8	*0.0*	13.8	-13.1	-344.9	0.0
16	90	*0.0*	13.3	*0.0*	13.3	-16.0	-664.0	0.0
17	90	*0.0*	12.7	*0.0*	12.7	-18.3	-778.0	0.0
18	110	*0.0*	12.5	*0.0*	0.0 (-12.5)	-11.8	-783.9 (438.8)	438.8
19	70	*0.0*	12.5	*0.0*	25.0 (12.5)	-25.6	-370.8 (62.7)	62.7
20	40	*0.0*	12.1	*0.0*	12.1	-17.8	546.3	0.0
21	40	*0.0*	11.6	*0.0*	11.6	-14.1	415.3	0.0
22	38	*0.0*	10.6	*0.0*	10.6	-4.1	118.8	0.0
23	38	*24.3*	10.3	*0.0* *(-24.3)*	10.3	4.2	-111.3 (-558.5)	-898.4
24	37	*24.3*	8.0	*0.0* *(-24.3)*	8.0	21.0	-500.4 (-582.7)	-922.7
SUM							**-4691.5 (647.1)**	**647.1**

Table 5.1 shows the hours where an increase or a decrease in the CG1 and CG2 consumption takes place as a result of the primary and secondary effects of the planned

DER control actions by yellow and light yellow backgrounds, respectively. In the above table, similarly as in the following tables, these colour codes are used. In addition, the CG1 consumption is presented in italics, and the estimated changes in the consumptions, risks, or cash flows resulting from planned of implemented DER control actions are indicated by red values in brackets. In other words, a red value represents changes in the values resulting from allocated control actions compared with the values before the allocation of control actions. The expected changes in the retailer's profits as a result of the control actions are presented in the last columns. The last row shows the sums of the last two column values.

Based on Figure 5.5 and Table 5.1, it can be seen that the control actions allocated for CG1 result in an estimated 24.3 MWh/h decrease in the consumption in hours 23 and 24 and a corresponding increase in hours 4 and 5. The CG2 control actions, in turn, result in about a 12.5 MWh decrease in the consumption of hour 18, and an equal increase in hour 19. The retailer's risks, presented by a relative hourly open position, do not exceed the applied $\pm$ 30 % risk constraint in any hour of the day. Therefore, the control actions can be implemented without violating the applied volume risk constraint.

According to the applied 100 €/MWh price spike constraint, a price spike is indicated at hour 18, the price of which is presented with a red background. Therefore, special attention is paid to the planning of DER control actions in hour 18. There is no specific DER control strategy to be applied for CG1 regarding the price spike, because CG1 has no consumption at that time. Because the forecasted price in hour 18 is higher than in hour 19, it is optimal to allocate a CG2 load disconnection in hour 18. This control action is also in line with the applied control and risk constraints. The control constraint of Equation (5.5) for at least a 20 €/MWh price difference for consecutive hours holds also between hours 19 and 20. However, the payback effect of the CG2 load disconnection in hour 18 takes place in hour 19, and thus, prevents the load disconnection in hour 19 (constraint (4.26). Consequently, only the load disconnection in hour 18 is allocated to CG2.

As a result of the planned control actions, the estimated total profile cost risk of open position changes from -5338.7 € to -4691.5 €. This indicates about a 647 € decrease in the expected Elspot purchase costs, in which approximately 146 € results in CG1 control actions and 502 € results in the CG2 control. It is notable that CG2 control actions result in an increase in the retailer's profits not only in hour 18, but also in hour 19. This is explained by the fact that in hour 18 the retail sales price is lower than the Elspot price, and thereby, a decrease in consumption results in an increase in profits. In hour 19, on the other hand, the retail sales price is higher than the Elspot price, and therefore, an increase in consumption increases the profits. The estimated decrease in the retailer's total Elspot purchase costs equals the increase in the retailer's expected total profits. This means that savings in the Elspot purchase costs are directly reflected to the retailer's profits. The first reason for this is that the retailer's total consumption does not change as a result of applied DER control actions, but only shifts between hours of the day. The second reason is that the retailer sells energy to the retail customer with fixed rates, that is, flat tariffs.

5.4.2 Elspot offers

After the retailer has drawn up the preliminary DER control plan, the retailer starts to plan offers (bids) to the Elspot. The first step in the drawing up of an Elspot trading plan is to review the allocated DER control actions in the consumption forecast. This updated load profile is the main input for planning of the Elspot trades, and can provide useful information for the determination of the optimal bidding strategy. The main question in the planning of Elspot trades is how much to trade in each hour. A practical solution from the perspective of risk management is to aim to trade in each hour the energy indicated by the physical open position. This way, the need for further balancing trades and the risks associated with future price variations are minimized. On the other hand, also variations in Elspot prices and opportunities to exploit them by allocating controllable DER after Elspot trades should be considered. Moreover, not only the allocated DER control actions but also their secondary effects have to be analysed.

By taking account of the above, the retailer draws up “a price elastic” Elspot trading plan. The basic principle is to buy slightly more than indicated by the physical open position if the price is unusually low, and buy slightly less than indicated by the physical open position if the price is exceptionally high. However, in hours where DER control actions cannot be applied, the retailer aims to buy rather precisely the amount indicated by the physical open position. This way, the retailer aims to minimize the imbalance risk at times when the power balance cannot be managed by DER control actions after the Elspot trades. Instead, at the times when the reverse holds, the aim is to take advantage of the Elspot price variations and manage the resulting imbalance risk after the Elspot trades by making trades in Elbas or using the DER available. Finally, based on the derived Elspot trading plan, the retailer places offers to the Elspot market, at the latest 12:00 CET.

5.4.3 Summary of Elspot trading

Finally, the retailer’s actions in stage 1, that is, planning of Elspot trades, are summarized in a chronological order as follows:

1. Update the consumption and price forecasts for the next delivery day. The updated load profile, in which each control group control potential (consumption) is shown, and the Elspot price forecast are the main input data for planning of the future operation.
2. Assess the applicability of the available DER capacity to different markets and analyse the risks involved in the DER control actions of different control groups in various markets.
3. Draw up a preliminary short-term DER control plan. Allocate available DER capacity initially based on the estimated Elspot price and consumption forecasts, considering the applied constraint and taking into account the risks and profit-making opportunities of different control actions.
4. Update the load profile with respect to the allocated control actions. Use this and recent Elspot price forecasts as the input data for planning the Elspot offers. In

general, aim to minimize the need for further balancing trades, but examine also options to take advantage of the Elspot price variations.

5. Place bids to the Elspot market, 12:00 CET at the latest.

5.5 Stage 2: Elspot results and initial planning of balancing operations

The next main step in the retailer's short-term operation is the analysis of Elspot results, based on which the initial planning of balancing operations is accomplished. The Elspot results are considered in the following section.

5.5.1 Elspot results

The Nord Pool Spot publishes Elspot system and area prices around 13:00 CET, and the retailer gets information about the realized Elspot prices and trades. The retailer's cash flows from the realized Elspot trades in day *d* are calculated as

$$C_{\mathrm{els}}(d) = \sum_{t=1}^{24} E_{\mathrm{els}}(t) * p_{\mathrm{els}}(t) \tag{5.11}$$

where

$C_{\mathrm{els}}(d)$	retailer's cash flows from day *d* Elspot trades
$E_{\mathrm{els}}(t)$	energy traded in the Elspot market in hour *t*

Based on the data of realized trades and the recent consumption forecasts, the retailer evaluates preliminarily the need for balancing operations, that is, the DER control and trades in the Elbas market required to reach the power balance. The need for balancing operations in hour *t* is shown by the physical open position of the hour in question, which is calculated after the Elspot trades as

$$E_{\mathrm{pop}}(t) = \left(E_{\mathrm{ph}}(t) + E_{\mathrm{els}}(t)\right) - E_{\mathrm{tot}}(t) \tag{5.12}$$

$E_{\mathrm{ph}}(t)$	energy traded (contracted) in physical delivery contracts in hour *t*
E_{tot} (t)	retailer's total consumption (estimated) in hour *t*

Especially very high physical open positions, which indicate a high imbalance risk, have to be identified in this stage of operation. This way, the required balancing operations can be planned and implemented in time in order to manage the highest risks.

5.5.2 Preliminary planning of balancing operations

The Elbas market provides a viable tool for balancing all or some of the imbalance that the retailer may have after the Elspot trades. Trading in the Elbas market opens for the next day delivery hours around 14:00 CET, and thus, the retailer has many hours to make the required balancing trades until the trading of a delivery hour closes one hour before the start of the delivery hour. It should be noted that Elbas is designed for balancing trades, and differs from Elspot trading. In Elbas, the prices are set based on a first-come, first-served principle. The lowest sell price and the highest buy price come first, and transactions are matched automatically as soon as concurring. This enables the retailer to actively follow the market and to benefit from the emerging trading opportunities.

From the viewpoint of the profit maximization objective, the retailer should aim to minimize the estimated Elbas purchase costs, in other words, to maximize the expected profits. This indicates that the same objectives are valid as in the Elspot trading stages, summarized by Equations (5.1) and (5.3). However, since the balancing operations are now in question, the main focus is on the management of the imbalance risk. From a practical point of view, this typically means minimization of the physical open position, as the future imbalance power prices are typically unpredictable.

The proposed strategy for the initial planning of balancing operations is based on the idea that the risks are managed by first setting appropriate risk constraints. In order to manage risks within the set constraints, the retailer starts planning of the balancing operation right after the Elspot trading results are known. The retailer first updates the consumption forecasts and evaluates the physical open position in each hour of the day. Because the time period for the accomplishment of the balancing operations is many hours, the retailer continuously follows the market movements and changes in the operating conditions, and adjusts its operation plan accordingly. The primary aim is to minimize the physical open position and the resulting imbalance risk by making trades in Elbas. However, there may not always be feasible trading opportunities in Elbas. In this case, the opportunities to use the available DER control capacity for balancing operations are taken. If there are neither DER capacity available nor opportunities for satisfactory Elbas trades, less advantageous Elbas trades or imbalance power trades have to be made. In addition to the above-described risk management approach, the retailer aims to exploit the emerging Elbas trading and other future profit-making opportunities in order to maximize the profits. If the retailer is able to forecast future prices in different markets reliably enough, the forecasts can be exploited. However, there may be only indications of future prices.

As presented in section 5.4, if there is no clear need to use the available DER control capacity in the current stage of operation, either from the risk management or profit maximization perspective, it should be preserved for the later stages of operation. This way, the available capacity can be offered in the reserve markets, which can provide great profit-making opportunities, or used close to the delivery in the balance management. Consequently, the proposed strategy, in which the retailer's primary aim is to accomplish the required balancing operation by making trades in Elbas and DER actions are used for this purpose only if the balancing trades cannot be completed, allows the retailer also to benefit from the available residual DER capacity in later stages of operation. Based on the above, we may state that although there can be more profitable strategies for the planning of the balancing operation, their implementation would require an ability to forecast future prices accurately. Otherwise, the retailer is exposed to substantial risks.

The proposed strategy, however, enables management of risks, still allowing the retailer to exploit the future profit-making opportunities provided by DER control actions.

According to the proposed operation strategy, the retailer first limits its risk exposure by applying risk constraints. Because the future prices include high uncertainties, it is advisable to use a volumetric risk measure. Physical open position is applied to measure the current volume (imbalance) risk exposure. Here, the following illustrative risk constraint is applied to the allowed imbalance risk exposure

$$-10\ \mathrm{MWh}\ \leq E_{\mathrm{pop}}(t) \leq\ 10\ \mathrm{MWh} \tag{5.13}$$

If the retailer's imbalance risk after Elspot trades in some hour is outside the set risk constraints, the retailer initially allocates balancing DER control actions so that the risk exposure can be managed at an acceptable level, as far as this is possible in terms of DER control capacity available. This aims to ensure that the highest imbalance risks can be managed by DER control actions if the risks cannot be managed by making Elbas trades.

After feasible risk constraints are placed, the retailer plans balancing DER actions and then starts to search for trading opportunities in Elbas. As soon as the retailer is able to make advantageous, or at least acceptable trades that balance the imbalances within the set risk constraints, the trades are completed. Always when a trade in Elbas is completed, the DER control plan is adjusted accordingly. If the risk exposure in some hour is managed within the imbalance constraints as a result of the Elbas trades made, the capacity that was allocated initially for balancing DER control actions at a particular hour is released for later use. However, if such balancing trades cannot be made, the retailer keeps the allocation unchanged. The final decisions regarding the balancing operations have to be made one hour prior to the start of the delivery hour, at the latest. The final decision-making regarding the balancing operations is presented later in section 5.8.

In addition to the above-described imbalance risk management, the retailer actively searches advantageous trading opportunities in Elbas to also manage the physical open position in hours that have a lower imbalance risk. The basic aim also here is to minimize the physical open position. If profit-making opportunities, for instance through imbalance trades, are indicated, the retailer can adjust its operation accordingly. For example, the physical open position can be adjusted slightly positive or negative in order to take advantage of the indicated imbalance power price variations. However, in any case, the aim is to maintain the imbalance risk within the set risk constraint. Figure 5.6 presents the retailer's load profile after the initial planning of the balancing operations, and Appendix C presents in detail the data on which the load profile is based.

Table 5.2. shows more detailed data of the retailer's estimated consumptions, current physical electricity procurements, and the physical open position. In addition, the Elspot price forecast that was used as the input for the planning of Elspot trades and the actual Elspot prices are presented.

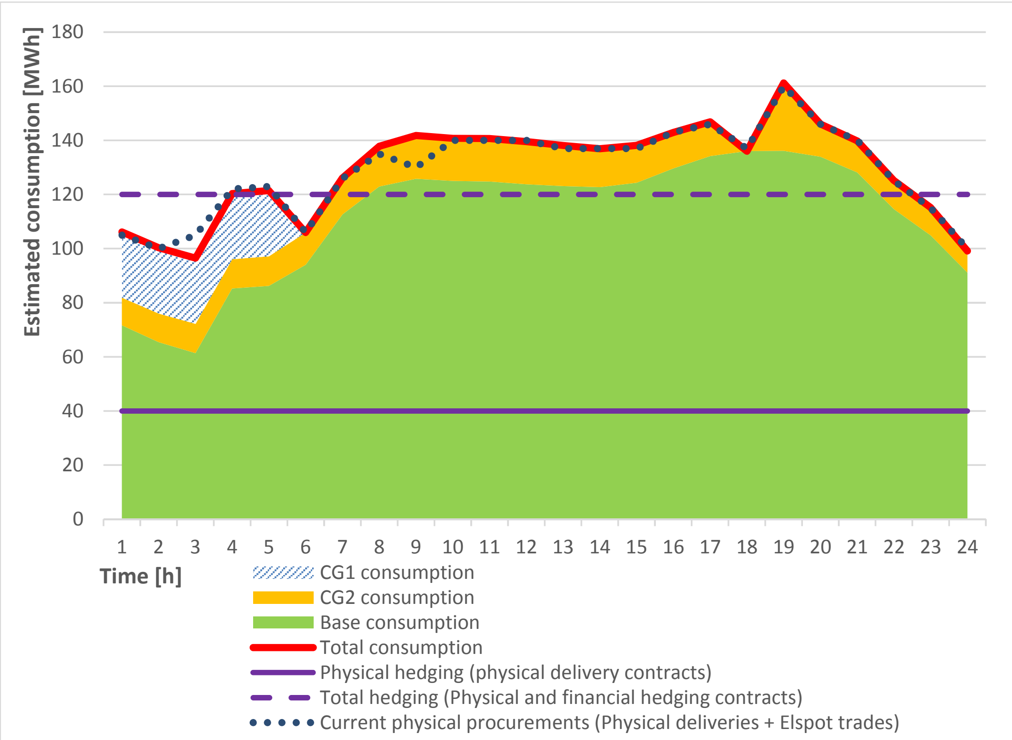

Figure 5.6. Retailer’s estimated load profile after Elspot trading.

Table 5.2. Retailer's estimated consumptions, current physical procurements, and physical open position after Elspot trades and initial planning of the balancing operation. Forecasted and actual Elspot price.

Hour	Forecasted Elspot price [€/MWh]	Actual Elspot price [€/MWh]	Total cons. [MWh]	Current physical procurements (Elspot trades + physical delivery contracts) [MWh]	Physical open position [MWh]	*CG1 cons. [MWh]*	CG2 cons. [MWh]
1	31	32.5	106.2	105.0	-1.2	*24.3*	10.2
2	31	32.4	100.3	100.0	-0.3	*24.3*	10.6
3	32	32.6	96.5	105.0	8.5	*24.3*	10.9
4	34	33.9	120.4	122.0	1.6	*24.3 (-24.3)*	10.8
5	35	35.9	121.4	123.0	1.6	*24.3 (-24.3)*	10.9
6	45	50.0	106.0	106.0	0.0	*0*	11.9
7	60	79.8	126.1	126.0	-0.1	*0*	13.5
8	70	78.6	137.8	135.0	-2.8	*0*	14.9
9	67	92.0	141.8	130.0	-11.8	*0*	16.0
10	65	69.9	140.8	140.0	-0.8	*0*	15.7
11	62	61.2	140.6	140.0	-0.6	*0*	15.9
12	56	58.8	139.5	140.0	0.5	*0*	15.8
13	56	56.1	138.1	137.0	-1.1	*0*	15.0
14	70	77.7	136.9	137.0	0.1	*0*	14.2
15	80	88.4	138.2	137.0	-1.1	*0*	13.8
16	90	98.5	142.9	143.0	0.1	*0*	13.3
17	90	90.0	146.8	146.0	-0.8	*0*	12.7
18	110	120.0	136.0	137.0	1.0	*0*	0.0 (-12.5)
19	70	80.8	161.2	160.0	-1.2	*0*	25.0 (12.5)
20	40	40.5	146.0	146.0	0.0	*0*	12.1
21	40	39.5	139.8	140.0	0.2	*0*	11.6
22	38	37.0	125.2	125.0	-0.2	*0*	10.6
23	38	36.7	115.2	115.0	-0.2	*0 -(24.3)*	10.3
24	37	36.1	99.2	100.0	0.8	*0 (-24.3)*	8.0

In Table 5.2, the retailer's hourly physical open positions that exceed the set risk limit are indicated by a red background. The DER control actions that are allocated during the prior short-term operation are presented using the same colour codes as in the previous tables. In addition, the control action allocated to the hour and control constraint (4.26) limits the allocation of new control actions to hour 17, which is illustrated by the blue background.

Compared with the base case (no control actions allocated), the CG2 consumption in hour 18 and the CG1 consumption in hours 23 and 24 decrease as a result of the primary effects of the allocated control actions. Correspondingly, the CG2 consumption in hour 19 and the CG1 consumption in hours 4 and 5 increase as a result of the secondary effects of the allocated control actions.

The retailer's physical open position in hour 9 is -11.8 MWh, and thus exceeds the set $\pm$ 10 MWh imbalance risk constraint. CG1 has no consumption in hour 9, and therefore, only the CG2 capacity can be used to decrease the physical open position of this hour. In order to manage the physical open position of hour 9 within the set imbalance risk constraint without violating the risk constraint in hour 10, the retailer preliminarily allocates -5.5 MWh control to hour 9 that balances the imbalance risk evenly between hours 9 and 10.

The imbalance risk in hour 3 is also high, but within the set risk constraints. Hence, the retailer pays attention to the hour 3 balancing trades in Elbas, but does not allocate DER control actions to the hour. The physical open positions in other hours of the day are relatively small, and thus, there is no substantial need for a balancing operation at these hours. However, if advantageous trading opportunities in Elbas or indications of other profit-making opportunities emerge, the retailer adjusts the physical open positions at these hours accordingly, but, in any case, within the set risk constraints.

Based on the above, we may state that the proposed strategy for the retailer operation after the Elspot trades is designed for the management of the imbalance risk. By first applying suitable risk constraints and then allocating available DER control capacity in an hour that exceeds the set imbalance risk limits, the risk can be managed within acceptable limits even if Elbas trades cannot be established. Still, the approach makes it possible also to exploit the emerging advantageous Elbas trading opportunities, and other future profit-making opportunities. Moreover, the basic strategy can be adjusted based on the risk preferences of the retailer under consideration by setting the risk constraints accordingly.

5.5.3 Summary of Elspot results and preliminary planning of balancing operations

The retailer operation in stage 2, Elspot results, and preliminary planning of balancing operations, is summarized in a chronological order as follows:

1. Update the consumption and price forecasts after the realized Elspot prices and trades are announced around 13:00 CET.
2. Start to plan the balancing operations right after the load profile is updated in order to use the trading opportunities emerging in Elbas during the whole trading period.
3. Define the risk constraints if they have not been determined in advance. Pay particular attention to the management of imbalance risks.
4. Estimate the current imbalance risks in different hours of the day.

5. Plan initially the balancing DER control actions that can be used to manage the risks within the set risk constraints. This allows the management of the imbalance risk if the balancing trades in Elbas are unsuccessful.
6. Follow the market movements. If advantageous trading opportunities emerge in Elbas, exploit them, and adjust the current DER control plan accordingly. Aim to accomplish the required balancing operations in Elbas in order to preserve the available DER to the later use. If advantageous trading opportunities do not emerge in Elbas, the final balancing operations can be postponed close to the end of the Elbas trading. The decision-making regarding the last-moment balancing operations is presented in section 5.8.

5.6 Stage 3: Planning of reserve market trades

After the preliminary planning of balancing operations, the next step in the retailer’s short-term operation is planning of reserve market trades. As introduced above, in this study, the focus is on the use of DER through hourly reserve markets, whereas options to offer DER in reserve use through yearly and long-term agreements are not studied. Each reserve type has its corresponding hourly market that Fingrid uses to acquire the reserve capacity needed for the specific reserve use. Here, the abbreviations of reserve products, which are introduced in Figure 2.3, are used to refer to the corresponding hourly markets. As each reserve is designed for a specific purpose, also each hourly reserve market sets requirements of its own for the offered capacity, which are summarized in Table 2.1. Therefore, the use of the DER capacity that is offered and accepted in a market depends mainly on the specific purpose of the use of the reserve. Consequently, also the expected profits and risks associated with the use of DER in different reserve markets can vary considerably, which has to be considered when planning offers to the reserve markets.

From the perspective of the optimal use of the available DER capacity, it is important to bear in mind that deadlines vary for placing the offers and times when the accepted offers are announced in different hourly reserve markets. Bids for the next day delivery hours must be submitted by 17:00 EET in the FRR-A market, and Fingrid confirms accepted offers 18:05 at the latest. Bids in the frequency containment reserve markets have to be submitted 18:30 at the latest, and Fingrid announces the accepted trades by 22:00. The deadline for submitting binding offers in the balancing power market (FRR-M) is 45 minutes before the start of the delivery. Because the deadline of balancing power market offers is close to the start of the delivery hour, the use of the controllable DER capacity in the balancing power market is discussed in more detail in section 5.8.

5.6.1 Applicability of DER to different reserve uses

The first step in the planning of DER control actions in the hourly reserve markets is a careful consideration of the applicability of different DERs to different reserve uses. In this context, both the requirements set by market rules (contract terms) and the control and consumption dynamics of the applied DER have to be addressed. In addition, risks associated with the reserve use DER have to be dealt with simultaneously. Special attention has to be paid to the availability of the DER capacity to the reserve use and the impacts of the secondary effects of the DER control actions.

The DER control actions implemented in a reserve use can result in secondary effects that limit the use of the available control capacity in the following hour(s) and expose the retailer to uncompensated power imbalances. In general, power imbalances caused by the primary effects of control actions applied in the reserve use during the delivery hour are compensated for according to the reserve market agreements in the imbalance settlement. However, power imbalances caused by the secondary effects of control actions are not compensated this way, if they take place outside the delivery hour. This means that the retailer has to implement balancing operations in order to manage the resulting imbalance risks. However, it is not known in advance how the capacity accepted in the reserve markets is used at the time of delivery, and thus, it can be very challenging to plan and implement the required balancing operations. Consequently, it is essential to analyse in detail the probable impacts of the reserve use, and to plan how the risks related to the uncompensated imbalances can be managed. Before studying these aspects in more detail, it is still pointed out that the use of the retailer's DER capacities in the FCR-N market is not addressed here, since it requires bi-directional control, as discussed above

The most prominent application for the use of the CG1 control capacity, by taking into account the risks associated with different reserve uses, is FCR-D. The retailer can offer CG1 capacity to the FCR-D use in all hours of the day that have capacity available, because the potentially implemented control actions are typically rather short (e.g. some minutes) and low in terms of the regulated energy. Therefore, they result in only modest secondary effects compared with control actions that are implemented in the FRR reserve uses. The CG1 control capacity can also be offered for up-regulation (load disconnection) in the FRR-A or FRR-M markets, but this sets requirements for a higher available control capacity, and can result in high secondary effects that pose risks of their own. The CG2 capacity is also most feasible to offer to the FCR-D use, because the expected payback effects caused by the control actions are lowest in this reserve use. It is also possible to offer CG2 capacity to the FRR uses, if there is adequate capacity available, but the payback effects of the control actions can pose serious risks for the retailer.

CG1 or CG2 load disconnections applied to reserve use always result in secondary effects, in other words, an increase in the heating load consumption in some other time. Because a CG1 load has a high energy storage capacity, the retailer can flexibly allocate the secondary effect of the CG1 load control to any hour of the day, as long as the total heating demand of the customers within the day is satisfied. Consequently, the retailer can manage the imbalance risk caused by the CG1 control actions quite well, if the implemented control actions can be verified in real time. This allows the retailer to plan balancing trades in Elbas accurately and allocate the substitute heating load consumption (secondary effects) accordingly.

The secondary effect of CG2 control actions takes place immediately after the end of the primary effect of the control. This limits the retailer's ability to manage the resulting imbalance risk, even if the applied control actions can be verified in real time. This is because the substitute heating load consumption cannot be allocated to later hours of the day similarly as for CG1 control actions. This, again, poses challenges to the planning of the balancing operations required to manage the resulting imbalance risk. For instance, the Elbas trades may no longer be accomplished in the hour where they occur.

The secondary effects of DER control actions, especially in the case of CG2 control actions, pose further challenges for the planning of the reserve use of controllable DER. In the case of CG2 control actions, it has to be borne in mind that if a load connection is implemented in one hour, the same capacity cannot be used to implement a new disconnection before adequate load recovery (payback effect) has taken place. If a disconnection of one hour is applied in hour t, a new disconnection during the following hour t+1 and the preceding hour (t-1) cannot be applied according to the control constraints of CG2. Assuming that there is now about the same volume of CG2 control capacity available in each hour of the day, the retailer can only offer half of the available CG2 capacity to the reserve for each hour of the day, or offer the whole capacity to the every second hour of the day to make sure that the required control actions can be implemented within the control constraints. Consequently, it is crucial to analyse not only the previously planned control actions, but also the impacts of the possibly accepted offers and the following control actions when planning offers to the reserve markets.

Based on the above analyses, we may state that the first prerequisite for planning of the offers in the reserve markets is the consideration of the requirements set by different marketplaces for the offered capacity. In addition, it is important to consider the risks involved in different types of DER control actions. For the retailer in question, the use of the DER control capacity of CG1 or CG2 in the FCR-D poses a lower risk than the control actions implemented in the FRR-M or FRR-A. CG1 control actions also usually pose lower risks than CG2 control actions for the retailer. By carefully elaborating on these aspects, the retailer is better able to manage the risks involved in the reserve use of DER.

To sum up, planning of the reserve use of DER calls for a detailed analysis of the consumption and control dynamics of the applied DER. These analyses yield valuable data for planning of the optimal DER control actions in the reserve use. Based on the analyses, the applicability of the DER capacities to different reserve uses can be estimated, and the associated risks evaluated. In addition, based on the detailed analyses, for instance the DER control constraints can be defined in more detail market and control group specifically so that there are no extra safety margins, or other such deficiencies, which make the use of the available DER control capacity less optimal. However, such detailed analyses are beyond the scope of this work. Therefore, the DER control actions in the reserve markets are planned by applying adequate safety margins, which ensure that the planned control actions are realistic from the perspective of practical implementation. Although this can make the reserve use of the DER capacity less optimal, it does not compromise the validity of the proposed approach.

5.6.2 Determination of acceptable DER offers

DER offers in the reserve markets are planned based on the updated consumption (and price) forecasts. The retailer's current estimated load profile is presented in Figure 5.7, and the data based on which the load profile is compiled in Appendix D.

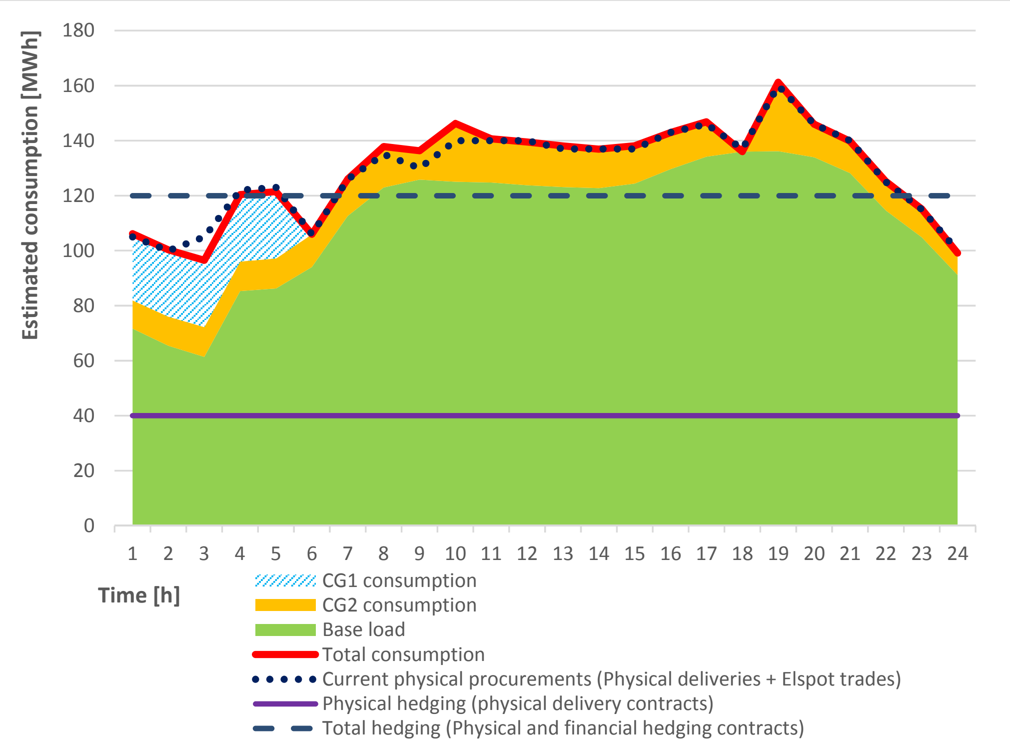

Figure 5.7. Retailer's estimated load profile before planning of the reserve market trades.

Next, the retailer starts to draw a list of acceptable DER control offers. This shows DER capacity available in different control groups at different times, and in which markets the capacities can be offered. The first step here is to consider the limitations set by previously allocated control actions and to estimate the residual DER control capacities available, as presented in Table 5.3.

Table 5.3. Retailer's estimated consumptions and residual DER capacities for reserve market offers.

Hour	**Total cons. [MWh]**	**CG1 total cons. [MWh]**	**CG1 residual control capacity [MWh]**	**CG1 residual control capacity [MW]**	**CG2 cons. [MWh]**	**CG2 residual control capacity [MWh]**	**CG2 residual control capacity [MW]**
1	106.2	*24.3*	*24.3*	17.0	10.2	10.2	7.2
2	100.3	*24.3*	*24.3*	17.0	10.6	10.6	7.4
3	96.5	*24.3*	*24.3*	17.0	10.9	10.9	7.6
4	120.4	*24.3 (24.3)*	*24.3*	17.0	10.8	10.8	7.6
5	121.4	*24.3 (24.3)*	*24.3*	17.0	10.9	10.9	7.7
6	106.0	*0.0*	*0.0*	0.0	11.9	11.9	8.3
7	126.1	*0.0*	*0.0*	0.0	13.5	13.5	9.4
8	137.8	*0.0*	*0.0*	0.0	14.9	14.9	10.4
9	136.3	*0.0*	*0.0*	0.0	10.5 (-5.5)	10.5	7.3
10	146.3	*0.0*	*0.0*	0.0	21.2 (5.5)	10.2	7.2
11	140.6	*0.0*	*0.0*	0.0	15.9	15.9	11.1
12	139.5	*0.0*	*0.0*	0.0	15.8	15.8	11.0
13	138.1	*0.0*	*0.0*	0.0	15.0	15.0	10.5
14	136.9	*0.0*	*0.0*	0.0	14.2	14.2	9.9
15	138.2	*0.0*	*0.0*	0.0	13.8	13.8	9.7
16	142.9	*0.0*	*0.0*	0.0	13.3	13.3	9.3
17	146.8	*0.0*	*0.0*	0.0	12.7	12.7	8.9
18	136.0	*0.0*	*0.0*	0.0	0.0 (-12.5)	0.0	0.0
19	161.2	*0.0*	*0.0*	0.0	25.0 (12.5)	0.0	0.0
20	146.0	*0.0*	*0.0*	0.0	12.1	12.1	8.4
21	139.8	*0.0*	*0.0*	0.0	11.6	11.6	8.1
22	125.2	*0.0*	*0.0*	0.0	10.6	10.6	7.4
23	115.2	*0.0 (24.3)*	*0.0*	0.0	10.3	10.3	7.2
24	99.2	*0.0 (24.3)*	*0.0*	0.0	8.0	8.0	5.6

Table 5.3 presents the retailer's estimated total, CG1, and CG2 consumption. In addition, the previously planned control actions and their estimated impacts on consumption are illustrated by using the same means of presentation as in the previous tables. By taking them into account, both control groups' residual control capacities are calculated and presented in terms of residual energy and power available in each hour.

The residual capacity is also estimated in terms of power, because the minimum capacity requirements of reserve markets are set with respect to the control power. The residual control powers given in Table 5.3 are calculated by adopting a 30 % safety margin between the average hourly consumption and the available control power, as presented in section 4.5.4. It is estimated that the hourly consumption compared with the minimum power required by a particular reserve has to be 30 % higher in order to make sure that the required control power is available at any instant during the hour.

Table 5.3 shows that the retailer has CG1 capacity available in hours 1–5, but not in any other hours of the day. Even though the CG1 consumption from hours 23 and 24 was shifted to hours 4 and 5, this does not set major limitations for the reserve use. This is because the CG1 consumption can be scheduled flexibly, and the allocated control actions were dealt with in the context of the Elspot electricity procurements. CG2 has residual capacity for all other hours of the day except for hours 17–19. The reason for this is that a control action was allocated for hour 18 in the Elspot trading, which prevents the implementation of control actions in hours 17–19. In addition, there is an initially allocated balancing control in hour 9, which similarly limits the use of the CG2 residual capacity in hours 8–10.

Based on these estimated residual DER control capacities, the retailer next determines in which reserve markets the available DER control capacities can be offered by considering the requirements set by different markets, before allocated control actions and control constraints. In particular, the requirements set by market rules for the volume of offered capacity and implementation and verification of control actions are important to analyse in detail. Here, it is assumed, as presented above, that the retailer under study can implement the required control actions by satisfying the requirements set by the markets. However, the capacity requirements set by the markets are taken into consideration separately. The minimum capacity requirements set by the FCR-D, FRR-A, and FRR-M are 1, 5, and 10 MW, respectively. Thus, if the retailer has control capacity available at least for the required amount in an hour, the capacity can be offered to the market(s). It should be noted that if a control group's available power is under the required minimum capacity limit of a market, the available capacity of the control group can still be used jointly with other control groups. However, for the sake of simplicity, this alternative is not discussed here. Based on the above analysis, a list of acceptable DER offers in the reserve markets is determined and presented in Table 5.4. It provides a simple and efficient basic tool for further planning of DER control actions in the reserve markets.

Table 5.4. List of acceptable DER offers in the reserve markets.

	CG1 control capacity that can be offered in reserve use [MW]			CG2 control capacity that can be offered in reserve use [MW]		
	FRR-A	FCR-D	FRR-M	FRR-A	FCR-D	FRR-M
1	*17.0*	*17.0*	*17.0*	7.2	7.2	7.2
2	*17.0*	*17.0*	*17.0*	7.4	7.4	7.4
3	*17.0*	*17.0*	*17.0*	7.6	7.6	7.6
4	*17.0*	*17.0*	*17.0*	7.6	7.6	7.6
5	*17.0*	*17.0*	*17.0*	7.7	7.7	7.7
6	*0.0*	*0.0*	*0.0*	8.3	8.3	8.3
7	*0.0*	*0.0*	*0.0*	9.4	9.4	9.4
8	*0.0*	*0.0*	*0.0*	10.4	10.4	10.4
9	*0.0*	*0.0*	*0.0*	7.3	7.3	7.3
10	*0.0*	*0.0*	*0.0*	7.2	7.2	7.2
11	*0.0*	*0.0*	*0.0*	11.1	11.1	11.1
12	*0.0*	*0.0*	*0.0*	11.0	11.0	11.0
13	*0.0*	*0.0*	*0.0*	10.5	10.5	10.5
14	*0.0*	*0.0*	*0.0*	9.9	9.9	9.9
15	*0.0*	*0.0*	*0.0*	9.7	9.7	9.7
16	*0.0*	*0.0*	*0.0*	9.3	9.3	9.3
17	*0.0*	*0.0*	*0.0*	8.9	8.9	8.9
18	*0.0*	*0.0*	*0.0*	0.0	0.0	0.0
19	*0.0*	*0.0*	*0.0*	0.0	0.0	0.0
20	*0.0*	*0.0*	*0.0*	8.4	8.4	8.4
21	*0.0*	*0.0*	*0.0*	8.1	8.1	8.1
22	*0.0*	*0.0*	*0.0*	7.4	7.4	7.4
23	*0.0*	*0.0*	*0.0*	7.2	7.2	7.2
24	*0.0*	*0.0*	*0.0*	5.6	5.6	5.6

The list of acceptable DER offers presents the CG1 and CG2 control power that can be offered in the reserve use in each hour. If the control power of an hour is lower than the minimum capacity limits of a particular market, and the offer cannot thus be placed for the market, the control power of the hour is presented by a red value. For the hours that have previously allocated control actions that can hinder the reserve use, the capacities are presented by using the same color codes as in the preceding tables. Consequently, control powers that are not presented by red values, and whose use is not limited by previous control actions, can be offered to a particular market as the table shows. However, the limitations that an accepted offer, in other words, the resulting use of the capacity and the payback effects may set are not addressed in the above table in order to enable the use of various bidding strategies. For instance, if the limitations set by the CG2 payback effect are considered in this stage by limiting the capacity that can be offered in a market at half of the total available capacity, this will prevent the use of an alternative strategy, in which the retailer offers the whole available capacity for every other hour.

5.6.3 Planning of a bidding strategy in reserve markets

The list of available DER control offers facilitates the final planning of the DER control offers in the reserve markets, although the retailer still faces the challenges in the determination of an advantageous bidding strategy. Obviously, if there is a reliable forecast available or at least indications of future reserve market prices, the bidding strategy should be planned by taking them into consideration, as discussed above. In any case, the offers have to be planned by analysing the risks related to uncertainties in future price and consumption forecasts, and to the reserve use of DER. Therefore, a low-risk bidding strategy, which also takes account of the options for sequential bidding, is proposed. In general, the strategy is based on the idea that the retailer offers available DER control capacity to various reserve markets with a rather high price in order to compensate for the associated risks, and considering the other above-discussed aspects. Finally, the price offers will be adjusted so that the higher is the risk associated with a particular reserve use, the higher is the placed offer price. In this context, it is also emphasized that the retailer's risk preferences significantly affect the placed offer.

The proposed sequential bidding strategy aims to exploit the multiple trading opportunities offered by the sequential operation of the hourly reserve markets. The retailer first places high-price offers of the available DER control capacity in the FRR-A market, 17:00 (EET) at the latest. The announcement of the accepted offers is given 18:05 at the latest. If the offer is not accepted, the retailer places a new high-price offer for the same capacity in the FCR-D (or FCR-N) market before the end of trading at 18:30. The information of the accepted bids in the FCR-D (or FCR-N) is given 22:00 at the latest. If the capacity is not accepted, again, the retailer can offer the same capacity in the balancing market until 45 minutes before the start of the delivery hour in question, or use it later for the balance management purposes. Consequently, the proposed sequential bidding strategy allows to exploit the profit-making opportunities offered by high prices in different reserve markets, but also to minimize risks involved in the DER control actions. However, a more detailed determination of the bidding strategy, in particular in terms of optimal bid prices or volumes, is beyond the scope of this work.

5.6.4 Summary of planning of reserve market trades

Stage 3, planning of the reserve market trades, is summarized in a chronological order as follows:

1. Study in detail the requirements set by different marketplaces and DER control constraints for the reserve use of DER.
2. Analyse the risks associated with different reserve uses for each control group.

3. Based on the updated consumption forecasts, estimate the available residual DER control capacities for each hour of the day.
4. Make a list of applicable DER control offers, which shows how much capacity in each hour of the day can be offered in each marketplace.
5. Plan a strategy for offering available DER control capacity to the hourly reserve markets. Assess the risks and profit-making opportunities of different offers and the resulting reserve use. Aim to take advantage of the sequential operation of the reserve markets. In order to compensate for the risks involved in different DER control actions, plan price offers that are high enough. The final offer price is adjusted based on the retailer’s risk preferences, remembering that the higher are the risks associated with the reserve use, the higher the offer price has to be.
6. Plan the placement of offers according to the operation sequence of the hourly reserve markets. Consider the deadlines for placing offers in different markets and announcement of accepted offers. Offer available DER control capacity first in the FRR-A market, next in the FRC-N and/or FRC-D markets, and finally, in the balancing market, or use it for balance management purposes.

5.7 Stage 4: Reserve market trading

In the next stage of the operation, the retailer starts to trade in the reserve markets following the basic sequential trading strategy, which was described in the previous section. The retailer places offers in the reserve markets, starting from FRR-A trades. When an offer is placed, the corresponding capacity is allocated preliminarily in the particular reserve use. If an offer to a market is accepted, the preliminary allocation of the capacity is confirmed, and if not, the retailer releases the capacity to the later use.

In the hourly reserve markets, the reserve prices are determined separately for each hour according to the pricing principles of the markets and the market parties’ offers. The impacts of the reserve use of DER on the retailer’s cash flows can be calculated accurately after the delivery, when the imposed regulations are known. Still, the impacts of the reserve use on the retailer’s cash flows can be estimated after the accepted offers and the hourly market prices are known. In particular, if the power component plays the main role in pricing of the reserve, the impacts of the reserve use on the retailer’s cash flows can be estimated quite accurately. The pricing principles of different reserve markets are given in Table 2.1.

5.7.1 Cash flow from the reserve use of DER

The retailer’s cash flows from trading and the use of DER control capacity in the hourly reserve markets in delivery hour *t* can be formulated as

$$C_{\text{res}}(t) = \sum_{rm} \left(P_{rm}(t) * p_{\text{P},rm}(t) + E_{rm}(t) * p_{\text{E},rm}(t) \right) \tag{5.14}$$

$$rm \in \{ \text{FCR} - \text{N}, \text{FCR} - \text{D}, \text{FRR} - \text{A}, \text{FRR} - \text{M} \}$$

$C_{\text{res}}(t)$ cash flows from the use of DER in hourly reserve markets in hour *t*
$P_{rm}(t)$ power (capacity) traded in reserve hour market rm in hour *t*
$p_{\text{P},rm}(t)$ power component of hourly reserve market rm price in hour *t*
$E_{rm}(t)$ energy traded in hourly market rm in hour *t*
$p_{\text{E},rm}(t)$ energy component of hourly reserve market rm price in hour *t*

with the following notations for index rm

FCR-N Frequency Containment Reserve for Normal operation
FRC-D Frequency Containment Reserve for Disturbances
FRR-A Automatic Frequency Restoration Reserve
FRR-M Manual Frequency Restoration Reserve (balancing market)

It is pointed out that the above equation takes into account the cash flows from the direct use of DER capacity in the reserve markets in delivery hour *t*. However, it does not take into account the indirect effects of the reserve use such as changes in the consumption resulting from a secondary effect of DER control actions outside delivery hour *t*.

Energy traded in a reserve market in hour *t* equals the energy controlled by DER as follows

$$E_{rm}(t) = E_{\Delta,\text{DER}}(t) \tag{5.15}$$

Therefore, cash flows from the secondary effects of DER control actions in hour t', resulting from the primary effects of control actions applied in hour *t*, are calculated as

$$C_{rm}(t') = \sum_{rm} \left(E_{\Delta,\text{DER}}(t') * p_{bm}(t') \right) \tag{5.16}$$

where

$E_{\Delta,\text{DER}}(t)$ change in the energy consumption in hour *t* as a result of the primary effects of DER control actions, applied at hour *t*
$E_{\Delta,\text{DER}}(t')$ change in the energy consumption in hour t′ as a result of the secondary effect of the DER control action, applied at hour *t*
$p_{bm}(t')$ Energy price in the balancing market *bm* (e.g. Elbas price or imbalance power price), in which the balancing trades in hour t' are made

When an offer is accepted to a market, the retailer reserves capacity to the particular use, and uses it to the regulations as defined by the reserve market agreement in question. The retailer’s cash flows from the reserve market trades depend on the hourly reserve market price and the DER capacity traded in the market. If the pricing is mainly based on the capacity in the market, the retailer is compensated mainly for the reservation of DER capacity for a specific reserve use. If the pricing is based mainly on the energy component, the retailer is paid for the sold energy, or pays for the purchased energy according to the current hourly market prices. If capacity is offered and used to up-regulation, the retailer sells energy to the market, whereas in the case of down-regulation, the retailer buys energy from the market. Therefore, the cash flows from reserve market trades can get either positive (profits) or negative values (costs), depending on whether the retailer sells or purchases energy.

For instance the use of DER capacity to the down-regulation in the balancing power market provides the retailer with an opportunity to purchase energy at a lower price than in Elspot. The up-regulation, again, may allow to sell energy to the balancing market at a higher price than in Elspot. The imbalances resulting from DER control actions at the delivery hour do not affect the cash flows from the reserve use when the retailer is compensated for them in the imbalance settlement. However, the secondary effects taking place outside the delivery hour have to be considered in the cash flow calculation, because they are not similarly compensated for.

5.7.2 Sequential trading in the hourly reserve markets

In a chronological order, trades in the FRR-A market take place first. The retailer under study places bids to the FRR-A 17:00 EET at the latest according the proposed basic bidding strategy and considering the capacity requirement of 5 MW. Fingrid announces the accepted offers 18:05 EET at the latest, and the retailer obtains the data of realized trades, that is, the capacities that are accepted to the reserve use and the prices of the capacities. Table 5.5 presents the retailer’s trades in the FRR-A market. The table shows the DER control capacities available in the market, accepted offers, and residual capacities that are available for a later use after the FRR-A market trades.

Table 5.5. Retailer's trades in the FRR-A market. Offered and accepted DER control capacities, and residual capacities available after the realized trades.

Hour	CG1 available DER control capacity in FRR-A market [MW]	CG2 available DER control capacity in FRR-A market [MW]	CG1 capacity offered in FFR-A market for up-regulation [MW]	CG2 capacity offered in FFR-A market for up-regulation [MW]	Offers accepted in FRR-A market [MW]	CG1 available residual capacity after FRR-A trades [MW]	CG2 available residual capacity after FRR-A trades [MW]
1	*17.0*	7.2	*15.0*	0.0	0.0	*17.0*	7.2
2	*17.0*	7.4	*15.0*	0.0	0.0	*17.0*	7.4
3	*17.0*	7.6	*15.0*	0.0	0.0	*17.0*	7.6
4	*17.0*	7.6	*15.0*	0.0	5.0 (CG1)	*12.0* *(-5)*	7.6
5	*17.0*	7.7	*15.0*	0.0	0.0	*17.0*	7.7
6	*0.0*	8.3	*0.0*	0.0	0.0	*0.0*	8.3
7	*0.0*	9.4	*0.0*	0.0	0.0	*0.0*	9.4
8	*0.0*	10.4	*0.0*	0.0	0.0	*0.0*	10.4
9	*0.0*	7.3	*0.0*	0.0	0.0	*0.0*	7.3
10	*0.0*	7.2	*0.0*	0.0	0.0	*0.0*	7.2
11	*0.0*	11.1	*0.0*	5.0	0.0	*0.0*	11.1
12	*0.0*	11.0	*0.0*	5.0	0.0	*0.0*	11.0
13	*0.0*	10.5	*0.0*	5.0	0.0	*0.0*	10.5
14	*0.0*	9.9	*0.0*	0.0	0.0	*0.0*	9.9
15	*0.0*	9.7	*0.0*	0.0	0.0	*0.0*	9.7
16	*0.0*	9.3	*0.0*	0.0	0.0	*0.0*	9.3
17	*0.0*	8.9	*0.0*	0.0	0.0	*0.0*	8.9
18	*0.0*	0.0	*0.0*	0.0	0.0	*0.0*	0.0
19	*0.0*	0.0	*0.0*	0.0	0.0	*0.0*	0.0
20	*0.0*	8.4	*0.0*	0.0	0.0	*0.0*	8.4
21	*0.0*	8.1	*0.0*	0.0	0.0	*0.0*	8.1
22	*0.0*	7.4	*0.0*	0.0	0.0	*0.0*	7.4
23	*0.0*	7.2	*0.0*	0.0	0.0	*0.0*	7.2
24	*0.0*	5.6	*0.0*	0.0	0.0	*0.0*	5.6

The past allocated DER control actions of CG2 are presented in Table 5.5 by the same colour codes as in the previous tables. The accepted offers are presented by red colour, and the control group whose capacity was offered is presented in brackets after the accepted offer. Similarly, the impact of the accepted offer on the residual capacity is presented by a red value in brackets. For illustrative purposes, in the above and following tables, the capacities that are allocated to the reserve use and the corresponding impacts on the residual capacities and consumptions are underlined. In addition, the changes in the available residual capacities after FRR-A trades are highlighted similarly as in the case of other allocated control actions. The yellow background indicates the primary effect, light yellow the secondary effect, and blue the additional limitations such as control restraints taking place at the hour in question.

The retailer places three 5 MW offers of the CG1 capacity available, offering thus a total of 15 MW to hours 1–5 for up-regulation in the FRR-A market. The offer prices are quite high, and therefore, only one 5 MW offer is accepted in hour 4. The retailer adopts an even more risk-averse bidding strategy when placing the CG2 offers because of the substantial imbalance risk associated with the payback effect of the CG2 control actions. Now, the retailer places a 5 MW offer of the CG2 capacity at a very high price in the consecutive hours 11–13, in which at least 10 MW of the CG2 control capacity is available. The target is to ensure that in the case of accepted offers, even if they take place in consecutive hours, the retailer has adequate capacity available to implement the required control actions. The high-offer price is set to compensate for the associated risks. However, this also leads to the rejection of all offers placed for the CG2 capacity.

Based on these FRR-A trading results, and considering the estimated impacts of the control actions resulting from the accepted offers, the retailer next updates the list of available residual control capacities. The DER control capacities that are accepted in the reserve use are also confirmed in the preliminary DER control plan, and the capacities that are not accepted are released for a later use. In this context, not only the primary effect but also the secondary effects of the control actions resulting from the reserve use of the capacity have to be considered. For instance, the accepted 5 MW offer of the CG1 capacity in hour 4 requires that when the loads are disconnected in the reserve use for up-regulation, the substitute heating load consumption must take place in some other time to ensure that the end-users' comfort is not compromised. In other words, the retailer has to allocate the substitute heating load consumption to some other time of day, which results in imbalance risks that have to managed, for instance, by making balancing trades in Elbas. These secondary effects and the management of the resulting imbalance risk are discussed in more detail in the following sections in the context of planning of the final balancing operations.

The next deadline for reserve market trades is 18:30 EET, when offers to the FRC-N and the FRC-D have to be placed at the latest. Similarly as in the case of FRR-A offers, the retailer places rather high price offers to compensate for the risks, and considers the minimum capacity limitations and DER control constraints to ensure the availability of DER to the reserve use. However, the prices of the FCR-D offers are somewhat lower than the prices of the FRR-A market offers, because the risks related to the DER use in the FCR-D are also lower, as discussed above. Table 5.6 presents the retailer's trades in the FCR-D hour market in the similar manner as in Table 5.5.

Table 5.6. Retailer's trades in the FCR-D hourly market. DER control capacities offered and accepted in the market and residual capacities available after the realized trades.

Hour	CG1 available DER control capacity in FRC-D market [MW]	CG2 available DER control capacity in FRC-D market [MW]	CG1 capacity offered in FRC-D market [MW]	CG2 capacity offered in FRC-D market [MW]	Offers accepted in FRC-D market [MW]	CG1 available residual capacity after FRC-D market trades [MW]	CG2 available residual capacity after FRC-D market trades [MW]
1	*17.0*	7.2	*17.0*	3.5	7.0 (CG1)	*10.0* (-7)	7.2
2	*17.0*	7.4	*17.0*	3.7	7.0 (CG1)	*10.0* (-7)	7.4
3	*17.0*	7.6	*17.0*	3.7	0.0	*17.0*	7.6
4	*12.0*	7.6	*12.0*	3.7	0.0	*12.0*	7.6
5	*17.0*	7.7	*17.0*	3.8	0.0	*17.0*	7.7
6	*0.0*	8.3	*0.0*	4.1	4.1 (CG2)	*0.0*	4.2 (-4.1)
7	*0.0*	9.4	*0.0*	4.7	0.0	*0.0*	5.3 (-4.1)
8	*0.0*	10.4	*0.0*	5.2	0.0	*0.0*	10.4
9	*0.0*	7.3	*0.0*	3.6	0.0	*0.0*	7.3
10	*0.0*	7.2	*0.0*	3.5	0.0	*0.0*	7.2
11	*0.0*	11.1	*0.0*	5.5	0.0	*0.0*	11.1
12	*0.0*	11.0	*0.0*	5.5	0.0	*0.0*	11.0
13	*0.0*	10.5	*0.0*	5.2	0.0	*0.0*	10.5
14	*0.0*	9.9	*0.0*	4.9	0.0	*0.0*	9.9
15	*0.0*	9.7	*0.0*	4.8	0.0	*0.0*	9.7
16	*0.0*	9.3	*0.0*	4.6	0.0	*0.0*	9.3
17	*0.0*	8.9	*0.0*	0.0	0.0	*0.0*	8.9
18	*0.0*	0.0	*0.0*	0.0	0.0	*0.0*	0.0
19	*0.0*	0.0	*0.0*	0.0	0.0	*0.0*	0.0
20	*0.0*	8.4	*0.0*	4.2	0.0	*0.0*	8.4
21	*0.0*	8.1	*0.0*	4.0	0.0	*0.0*	8.1
22	*0.0*	7.4	*0.0*	3.7	0.0	*0.0*	7.4
23	*0.0*	7.2	*0.0*	3.5	0.0	*0.0*	7.2
24	*0.0*	5.6	*0.0*	2.8	0.0	*0.0*	5.6

Because the risks involved in the FCR-D use of the CG1 capacity are rather low but the profit-making potential is considerably high, the retailer offers all available CG1 control capacity in the FCR-D market at a slightly lower price than at which the offers in the FRR-A market were placed. By considering the risk caused by the payback effect of the

CG2 control actions, the retailer offers about half of the CG2 control capacity available to the FCR-D market at a slightly higher price at all hours, within the constraints set by the previously allocated control action.

The retailer obtains information of the accepted offers from Fingrid at around 22:00. Two 7 MW offers placed for the CG1 capacity in hours 1 and 2 are accepted, and one 4.1 MW offer of the CG2 capacity in hour 6 is accepted in the FCR-D market. Similarly as in the case of FRR-A market trades, the retailer next updates the list of available control capacities, confirms the DER control actions according to the accepted offers in the preliminary DER control plan, and releases the rest of the capacity that was allocated preliminarily to the FCR-D use when submitting the offers. Here, as well as in the future, it is assumed that the use of the DER capacity offered and accepted in the FCR-D is minor, and therefore, it does not have a considerable effect on the retailer’s consumption. Nevertheless, the capacity has still to be allocated to the reserve use, and thereby decreases the available residual capacity at times when primary or secondary effects of control actions take place.

In Table 5.6, the values of the CG2 residual capacities are calculated by considering the worst-case scenario from the viewpoint of available capacities. If control actions are applied at the end of a delivery hour, the payback takes place at the beginning of the following hour, and therefore, also decreases the following hour’s residual capacity. The management of the imbalance risks resulting from the secondary effects of the DER control actions in the reserve use as well as the related modelling aspects are discussed in more detail in the following sections. The trades in the balancing power market are made close to the delivery, and are therefore introduced in the following sections.

5.7.3 Summary of reserve market trading

The retailer operation in the reserve market trading stage is summarized as follows:

1. Place bids according to the planned sequential bidding strategy first in the FRR-A market. Take into account the risks associated with the implementation of control actions, and in particular, their secondary effects, and opportunities to manage them when defining the offer prices.
2. If a placed offer is accepted in the FRR-A, update the list of available DER control capacities by considering the impacts of the secondary effects of the planned control actions. In addition, confirm the accepted offers in the preliminary DER control plan, and release the rest of the capacity that was allocated to the reserve use when submitting the offers.
3. Offer the available residual capacity in the FRC-N and/or FRC-D markets according to the planned bidding strategy.
4. Again, if a placed offer is accepted in the FRC-N and/or FRC-D, update the list of available DER control capacities and confirm the control in the DER control plan. If an offer is not accepted, release the capacity allocated preliminarily in the case of the acceptance of the offer.

5. Consider the risk of the DER control actions allocated to the reserve use, and especially their secondary effects, and update the operation plan accordingly. This and the last trades in the reserve markets, that is, the trades in the balancing markets, are described in the following sections.

5.8 Stage 5: Planning of balancing operations and balancing market trades

After the retailer has received an announcement of the accepted frequency containment reserve offers in hourly markets by 22:00 EET, the next step of the short-term profit optimization is to plan the balancing operations and the balancing power market trades. As discussed with the preliminary planning of balancing operations, the retailer first aims at making balancing trades in Elbas, but alternatively, the available DER capacity can be used in the balancing operations. Nevertheless, if the allocation of the DER control actions is more optimal, for instance as a result of the current load profile or scarcity of Elbas trading opportunities, the allocation of DER control actions is the primary option. On the other hand, if the risks are not high, it is advisable to wait for advantageous trading opportunities, even very close to the delivery. Moreover, waiting close to the end of Elbas trading allows the retailer to use the latest and thus presumably the most accurate forecasts available as inputs for planning of the final balancing operations.

5.8.1 Management of imbalance risk

As presented above, the preliminary plan for balancing operations is made right after the results of the Elspot trading results are known in order to make sure that the highest risks can be managed within an acceptable level as soon as this can be done in Elbas. However, the uncertainty related to the future consumption and price forecasts makes it challenging to plan the optimal balancing operations well in advance. Further, the consumption can be forecasted more accurately close to the delivery when the forecasting horizon is short. Therefore, the management of imbalance risks is based on the idea that the retailer actively updates the operation plan according to the most recent forecasts and data, which enables the retailer to plan its operation more accurately, and thereby minimize the imbalance risk and/or to exploit the emerging profit-making opportunities. Therefore, after the preliminary planning of the balancing operations, the retailer actively follows the Elbas market, exploits the emerging advantageous trading opportunities, and continuously updates its operation plan. Nevertheless, the final balancing operations including trades in Elbas and allocation of balancing DER control actions are performed close to the delivery.

A simple way to limit the risks when the moment of delivery approaches is to adjust the current risk constraints or set additional risk targets based on the current risk management needs. By aiming at small deviations of the physical open position, the retailer can keep its imbalance risk at a low level. Although the low allowed risk exposure limits the future profit-making opportunities, the importance of adequate risk management, the uncertainty of future imbalance power prices, and the decreasing future trading opportunities usually make it preferable to limit the risks to a rather low level close to the delivery. Therefore, the risk-averse retailer sets next the following additional imbalance risk target

$$-5\text{ MW} \leq E_{\text{pop}}(t) \leq 5\text{ MW} \tag{5.17}$$

The previous risk constraints of ± 10 MW on the allowed deviation of physical open positions are complemented by an additional risk target of ± 5 MW for hourly physical open positions. It is pointed out that this risk target, similarly to other applied risk constraints, is not optimized in detail, but implemented for illustrative purposes only.

After the retailer has adjusted its risk targets, it estimates the current risk exposure in more detail based on the recent consumption forecasts. Figure 5.8 presents the retailer's current forecasted load profile, and the data based on which the load profile is compiled in Appendix E. Table 5.7 lists the retailer's estimated consumptions, hourly physical open positions, and available residual DER control capacities.

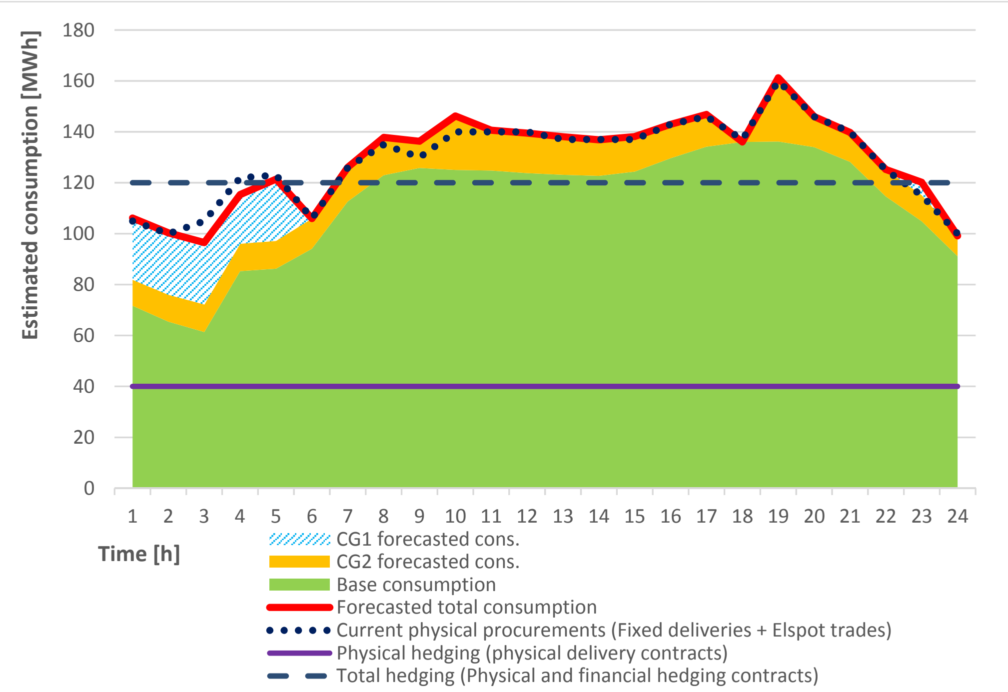

Figure 5.8. Retailer's current (forecasted) load profile.

Table 5.7. Retailer’s estimated consumptions, physical open position, and available residual DER control capacities.

Hour	Forecasted total cons. [MWh]	Physical open position [MWh]	CG1 forecasted cons. [MWh]	CG2 forecasted cons. [MWh]	CG1 residual DER control capacity [MW]	CG2 residual DER control capacity [MW]
1	106.2	-1.2	24.3	10.2	*10.0* *(-7)*	7.2
2	100.3	-0.3	24.3	10.6	*10.0* *(-7)*	7.4
3	96.5	8.5	24.3	10.9	*17.0*	7.6
4	115.4	1.6	19.3 *(-5)*	10.8	*12.0* *(-5)*	7.6
5	121.4	1.6	24.3	10.9	*17.0*	7.7
6	106.0	-4.1	0.0	11.9	*0.0*	4.2 (-4.1)
7	126.1	-0.1	0.0	13.5	*0.0*	5.3 (-4.1)
8	137.8	-2.8	0.0	14.9	*0.0*	10.4
9	136.3	-6.3	0.0	10.5	*0.0*	7.3
10	146.3	-6.3	0.0	21.2	*0.0*	7.2
11	140.6	-0.6	0.0	15.9	*0.0*	11.1
12	139.5	0.5	0.0	15.8	*0.0*	11.0
13	138.1	-1.1	0.0	15.0	*0.0*	10.5
14	136.9	0.1	0.0	14.2	*0.0*	9.9
15	138.2	-1.1	0.0	13.8	*0.0*	9.7
16	142.9	0.1	0.0	13.3	*0.0*	9.3
17	146.8	-0.8	0.0	12.7	*0.0*	8.9
18	136.0	1.0	0.0	0.0	*0.0*	0.0
19	161.2	-1.2	0.0	25.0	*0.0*	0.0
20	146.0	0.0	0.0	12.1	*0.0*	8.4
21	139.8	0.2	0.0	11.6	*0.0*	8.1
22	125.2	-0.2	0.0	10.6	*0.0*	7.4
23	120.2	-5.2	5.0 *(5)*	10.3	*0.0*	7.2
24	99.2	0.8	0.0	8.0	*0.0*	5.6

In Table 5.7, the retailer’s hourly physical open positions that exceed the set risk targets are illustrated with a red background. The allocated DER control actions and the changes in the retailer’s consumption resulting from them are presented in the table similarly as in the previous tables. However, for the sake of simplicity, only the changes resulting from DER control actions allocated to the reserve use are presented separately (red underlined values in brackets). It is also noted that the control actions allocated to the FCR-D use only affect the residual capacities but not the consumptions. This is because the capacity is kept for the reserve use, but it is estimated that it is used only slightly, if at all, to regulation.

As discussed above, if an offer of CG1 capacity is accepted to a reserve use, the retailer allocates the substitute heating load consumption to later hours of the day. However, the FCR-D reserve use makes an exception to this, because its impacts on the retailer's consumptions are assumed to be quite insignificant. Consequently, the retailer has preliminarily allocated 5 MWh of substitute heating load consumption in hour 23, illustrated by an orange background, to cover the FRR-A reserve use of CG1 in hour 4.

It is emphasized that the preliminary allocation of substitute heating load consumption at the end of the day is recommendable for several reasons. The first one is that when the control actions take place in earlier hours of the day, and are verified right after that, the retailer has enough time to update the current operation plan. The second reason is that the retailer is more likely to find advantageous purchase opportunities at last hours of the day, because the lowest prices generally take place at night-time. Finally, if advantageous Elbas purchases can be made after the realized DER control actions have been verified at some earlier hour of the day, the retailer can make the purchases first and then reallocate the substitute heating load at the hour in question.

Table 5.7 shows that the retailer's physical open positions exceed the set imbalance risk target at hours 3, 9, 10, and 23. In order to adjust these unfavourable physical open positions within the risk target, the retailer primarily aims to make balancing trades in Elbas. If the trades cannot be made before the end of the Elbas period, the retailer uses the DER control capacity available to the management of power balance, if possible.

It is pointed out that offers of residual DER control capacities to the balancing power market should be planned before the final plan for balancing operations is drawn up. This is because the impacts of the control actions allocated to the market have an effect on the retailer's consumption and the risks, which have to be considered before the final balancing operations can be planned accurately. On the other hand, also the needs and opportunities to use the residual DER in the balance management have to be studied before planning the balancing market offers. If this is not done, the capacity may be used in the balancing market, even if its use in the balancing operations had been more optimal. Therefore, the retailer first estimates the current needs and opportunities to use the residual DER in the balance management. Next, the retailer plans the offers in the balancing markets by examining the options and needs to use DER in the balance management. Finally, the retailer makes a detailed plan for the final balancing operations. The key issues to be analysed in the preliminary planning of balance management are discussed next.

5.8.1 Planning of balancing power market trades

After the consideration of preliminary needs and general requirements for balance management, the retailer plans the use of residual DER control capacity in the balancing power market. Similarly as in the planning of other reserve market trades, attention has to be paid to the requirements set for the offered DER capacity. For instance, the requirement of the 10 MW minimum capacity of the balancing power market sets considerably high limitations on the use of residual DER control capacity. Once again, the importance of the detailed consideration of the secondary effects of the DER control actions is highlighted, because the uncompensated power imbalances can pose a serious risk for the retailer.

As a result of the 10 MW minimum capacity requirement of the balancing market, the retailer under examination can offer the available CG2 control capacity for up-regulation in the balancing market only to hours 8 and 11–13 (see Table 5.7). By also considering the CG2 control constraints and previously allocated control actions, it is probably not a feasible option to offer the CG2 capacity in hour 8. This is because it is not known for certain whether the implementation of the 10 MW control in hour 8 results in such a high payback effect in hour 9 that it would hinder the implementation of the control action that was previously allocated to hour 9. By taking into account also the fact that the applied control constraints prevent the implementation of CG2 control actions in consecutive hours, the retailer can make offers of the available CG2 capacity in the balancing market only to hour 12, or alternatively, to hours 11 and 13.

The secondary effects of the CG2 control actions in the FRR-M use presumably take place after the delivery hour in question. Therefore, they result in a high risk for the retailer in the form of uncompensated imbalances. Furthermore, these imbalances cannot be managed by Elbas trades when the accepted offers and the realized reserve use are known only after the end of the Elbas trading of the particular hour. Consequently, it is proposed that a feasible strategy is to offer the CG2 residual capacity for up-regulation in the balancing market to hours 11 and 13 at a high price. This way, the risks caused by uncompensated imbalances are compensated for, at least to a great degree, by high expected profits of the reserve use.

An optimal strategy for the CG1 balancing market offers depends largely on the implementation of the control actions. It is assumed that the retailer can verify the implemented control actions in almost real time, and based on this data, flexibly reallocate the substitute heating load consumption to the later hours of the day. This allows the retailer to manage the resulting imbalance risk rather well, because balancing trades in Elbas can be made to compensate for the imbalances resulting from the reallocation of the substitute heating load consumption. Furthermore, this can even enable the retailer to benefit from the emerging low-price purchase opportunities in Elbas, as will be discussed later. By taking into account the above, the retailer can place offers to the balancing market in hours that have at least 10 MW of CG1 residual control capacity available. Since the associated risks can be managed appropriately, also the offer price can be considerably lower than in the case of CG2. Therefore, the retailer places 10 MW offers of the CG1 residual capacity to hours 1–5 by favouring medium and slightly higher price offers, and keeps the residual capacities for balance management purposes.

Bids to the balancing market can be placed from the beginning of the day preceding the delivery hour in question, and can be cancelled or changed until 45 minutes before the start of the delivery hour, after which the bids are binding. After the bids are placed, and announcements of accepted bids are obtained, the retailer adjusts its operation plan accordingly. If an offer of the CG1 capacity is accepted, the retailer confirms its allocation to the reserve use in DER control plan, estimates/verifies the impacts of the allocated control actions on consumption as soon as possible, and allocates the substitute heating load consumption to the last hours of the day. After this, the retailer follows the Elbas market and aims at making advantageous balancing purchases in Elbas to compensate for the imbalance resulting from the reallocation of the substitute heating load consumption. This way, the retailer can manage the power imbalance caused by the reserve use of CG1 at the target level, or at least at a more favourable level. Although the imbalance caused by the CG2 reserve use cannot be managed as adequately, it is compensated by high expected profits, which are due to the placed high-price offers.

5.8.2 Consideration of balance management aspects

Before the trading plan for the balancing market is made, the retailer evaluates preliminarily the needs and opportunities to use DER in the balance management. Table 5.7 shows that there are rather limited possibilities to manage the physical open positions that are outside the set risk targets by using residual DER capacity. The main reasons for this are the previously allocated CG2 control actions, low available residual control capacities and/or occurrences of unfavourable physical open positions compared with the available residual DER capacities. The DER control actions that are allocated to other purposes than reserve use can still be adjusted, but this can result in new imbalances and may not solve the issues related to the retailer's limited options to manage imbalances.

Although some adjustment to the physical open positions can be made, for instance by shifting the CG2 consumption and the resulting risk from one hour to another, the feasible alternatives for balancing operations are limited mainly to Elbas trades. From this viewpoint, basically all available residual capacities can be offered to the balancing market. In addition, considering the retailer's profit maximization objective, it is important to aim at the efficient use of the available residual DER control capacities. Therefore, the retailer aims at using residual capacities efficiently in the balancing market in order to maximize the expected profits. However, before drawing up the plan for the balancing market offers, other balance management aspects have to be addressed.

From the perspective of the retailer's risk management, especially the secondary effects of the DER control actions that can result in uncompensated imbalances (secondary effects that take place outside the delivery hour and are not compensated for according to the reserve market agreements in the balance settlement) have to be taken into account.

This is also supported by the observation made based on Table 5.7. Currently, the retailer's highest hourly imbalances (deviations in physical open positions) take place at the hours in which the primary or secondary effects of the allocated CG2 control actions take place, with the exclusion of hour 3. This indicates that the allocated CG2 DER control actions expose the retailer to a considerable imbalance risk.

In addition, the following requirements set by the balance service agreement (BSA, 2015) call for careful planning of the balance management:

- "Balance Responsible Party shall plan and control its power purchases and deliveries so that the hourly balance deviation remains reasonable with respect to Balance Responsible Party's scope of operations."
- "Balance Responsible Party shall not use open deliveries for systematic power purchase or sales."

Although the above requirements do not precisely define how much imbalance deviation a market party may have, it is obvious that high imbalance has to be avoided.

A guideline for the retailer's balance management is to aim at the minimization of power imbalances. Nevertheless, it is pointed out that the balance service agreement, or other market rules, does not prevent the retailer from occasional imbalance. Moreover, simply the fact that future consumption always includes some uncertainties leads to some imbalances. Consequently, the retailer can manage the power balance at a slightly positive or negative level, if this provides considerable profit-making opportunities, or is recommendable from the perspective of risk management. For instance, if a high imbalance power price is indicated to take place at a specific hour, the retailer has to aim at a slightly positive physical open position in order to avoid unprofitable imbalance power purchases. Still, price and demand uncertainties, the prevailing operating conditions and the payback effects of DER control actions can pose major challenges for optimal balance management, although the application of controllable DER provides feasible means for the last-moment adjustment of the power balance.

5.8.3 Planning of last-moment balancing operations

After the balancing power market trades are planned in detail, and their estimated (possible) impacts are taken into account in the current operation plan, the retailer makes a plan for the last-moment balancing operations. As described above, the retailer aims, in the first place, at making balancing trades in Elbas to manage the associated risks, which typically means minimization of the current physical open position. If clear indications of unusually high or low imbalances power prices occur, the retailer aims at a slightly positive or negative physical open position in order to take advantage of profitable imbalance power trades. Although this kind of balance management is usually rather challenging because of the uncertainties related to forecasting of imbalance power prices, in some cases, the retailer may be able to indicate the imbalance power prices reliably enough. Especially, close to the moment of delivery, these indications can be obtained based on the recent forecasts, considering the current operating conditions, market situations, and other such factors. Next, these specific issues are addressed in brief.

As discussed already in the previous sections, special operating conditions such as large production or transmission interruptions result in an increasing need for balancing power, which, in turn, raises the prices. For instance, a very high electricity demand because of cold weather can lead to a price rise. When this takes place simultaneously with a shortage in production capacity, very high prices can be expected. In addition to consideration of the special operating conditions, observation of the specific details of the market model and the pricing mechanisms can provide the retailer with reliable indications of unusually high prices and thereby bring substantial profit-making opportunities. The following example illustrates some key aspects of the balancing power market and imbalance power pricing mechanisms, which can enable the retailer to plan advantageous last-moment balancing operations.

Let us first assume that the realized Elspot price is high, and cold weather conditions clearly indicate a need for up-regulation. In this case, the up-regulation price in the balancing power market can be reliably forecasted to be at least as high as but probably even higher than the Elspot price. This is because the up-regulation price, which is also referred to as the upper balancing power price, is the price of the most expensive up-regulation bid used; however, it is at least the Elspot FIN, the price in the Finnish price area in Nord Pool Spot (Fingrid, 2015b).

Let us further assume that the retailer has offered capacity for up-regulation in the balancing power market, and Fingrid has confirmed the regulation and the price of the regulation. Therefore, the up-regulation price of the hour is the same or higher than the price confirmed by Fingrid. Hence, if the retailer has placed an offer that is accepted in the balancing market, this price information of the accepted offer can be exploited in the forecasting up-regulation and the imbalance power price, of which the latter is discussed in more detail next.

The price of the consumption imbalance power can also be evaluated in the example case based on the following pricing principles of imbalance power. The price of the consumption imbalance power in an up-regulating hour is the up-regulation price of the hour (Fingrid, 2015j). In this case, the hour is clearly an up-regulating hour, because the electricity demand is high and there is shortage of production. Thus, also the consumption imbalance power price of the hour is at least the same as the price confirmed by Fingrid for the up-regulation applied by the retailer. It is emphasized that although such operating conditions seldom take place, they can provide substantial profit-making opportunities for the retailer, and should thus be taken into account in the planning of operation close to the delivery.

To sum up, the retailer first plans its balance management carefully by taking into account the option to use DER in the balance management and considering the most significant risks and profit-making opportunities. This plan is then updated continuously based on the current operating and market situations. In the first place, the retailer aims at making advantageous balancing trades well in advance in order to manage the current imbalance risks. If reliable indications of future imbalance power prices are available, the retailer aims at a slightly positive or negative open position in order to avoid unprofitable imbalance trades or to benefit from profitable trades. In any case, the power balance is always adjusted within the set risk constraints/targets. Therefore, even less advantageous Elbas trades can be made just before the end of the trading period, if the risk constraints cannot be maintained otherwise. Furthermore, along with active balance management, the retailer operates in the balancing power market according to the derived trading plan. This, as well as other operation plans, are also updated continuously according to the changes taking place in the operating and market conditions.

5.8.4 Summary of balancing operation and balancing market trades

The retailer’s short-term operation in stage 5, planning of balancing operations and balancing market trades, is summarized as follows:

1. Adjust the risk constraints or define additional risk targets according to the current risk management needs. For instance, set an additional risk target for the allowed deviation of the physical open position in order to make sure that the risks are at an acceptable level when the moment of delivery approaches and available trading opportunities decrease.
2. Consider the preliminarily needs and opportunities to use residual DER control capacities available in the balance management.
3. Draw up a plan for the use of residual DER control capacity in the balancing power market by considering the above point (2) and the requirements set for the balance management. Take into account the risks associated with DER control actions that will be applied if the placed offers are accepted. Manage or compensate for the associated risks by planning the future operation accordingly and/or by setting an appropriate (adequate high) price for the offered DER capacity.
4. Plan in detail the last-moment balancing operations by considering the potential impacts of the accepted balancing market offers on the current imbalance risk. In general, aim to minimize the physical open position. Adjust the physical open position to be slightly negative or positive, if adequate reliable imbalance power price indications or other corresponding inputs are in favour of this.
5. Continue operation according to the current operation plan by aiming to exploit advantageous opportunities for Elbas trades and the use of residual DER capacity. Update the operation plans continuously based on the recent forecasts and changes in the market and the operating conditions.
6. Make trades in Elbas at the latest one hour, and in the balancing market 45 minutes before the start of the delivery hour in question at the latest.

5.9 Stage 6: Operation close to the delivery

After the start of a delivery hour, offers can no longer be placed to any market. Still, the retailer can use the residual DER control capacity to adjust its power balance all the way until the end of the delivery hour. Also previously allocated DER control actions, except for those allocated to the reserve use, can be adjusted. However, this can easily lead to unfavourable imbalances, and may thus not be a feasible alternative. Finally, imbalance power trades are accomplished and settled in the imbalance settlement, which takes place after the delivery.

5.9.1 Overview of operation close to the delivery

At the time of delivery, the retailer's main focus is on the balance management and implementation of the planned DER control actions. In addition, the retailer plans the following delivery hours' operation and verifies the implemented operations. Continuous updating of the operation plans based on the recent available data and forecasts is a prerequisite for dynamic adjustment of operation according to the changing operating and market conditions. In this context, attention is paid to the fast verification of DER control actions. In particular, the reserve use of DER, which can be very difficult to estimate in advance, has to be verified as close to real time as possible. This is necessitated by the general requirement that the control actions in the reserve use have to be verified reliably and almost in real time, for instance through measurements. Notably, fast and accurate verification of the primary and secondary effects of DER control actions can also enable the retailer to forecast more accurately the future consumptions and plan more precisely the required balancing operations.

Dynamic operation based on the latest consumption and price forecasts combined with fast verification of the applied DER control serves as a basis for the retailer's balance management close to and at the time of delivery. As presented in the previous section, by active balance management, the retailer aims to minimize the current imbalance risk and/or to exploit the emerging profit-making opportunities resulting from imbalance power price variations. Taking advantage of imbalance power price variations is a feasible strategy mainly if there are reliable indications of future prices, based on which the retailer can adjust its current physical open position to a slightly positive or negative level. Because these indications may be only rarely available, minimization of the imbalance risk by using the DER control capacity and making trades in Elbas for incoming hours are typically the most feasible strategy for the balance management.

The operations that are accomplished close to the delivery include balancing trades in the Elbas market at the latest hour before the start of a delivery hour, offers to the balancing market 45 minutes before the start of the delivery hour at the latest, and management of the power balance using the DER control capacity available during the delivery hour. During each delivery hour of the day, the retailer continuously monitors changes in the operating and market conditions and adjusts its operation plans accordingly. If possible, already at the time of delivery, or after each delivery hour at the latest, the impacts of implemented DER control actions are verified in detail, and used as input data when updating the operation plans. This operation sequence is repeated throughout the whole delivery day.

5.9.2 Retailer operation on the delivery day

During each delivery day, the retailer focuses mainly on the current and near-future operations. However, also earlier operations have to be taken into account, and the future operation must be planned also further ahead in the future. Consequently, various factors have to be considered simultaneously. The most important ones are the deadlines for making trades in different markets, which also set deadlines for planning the use of DER.

The retailer operations in each delivery hour are planned rather precisely in advance, as described in the previous sections. Nevertheless, it is essential to assess the verification of the realized operations and analyse the following updating of operation plans in the operating and market environment, where the situations may change quite rapidly. The considered retailer operation during the delivery day is summarized in Table 5.8, and will be described and analysed after that.

Table 5.8. Electricity retailer's operation during the delivery day.

Hour	Offers in balancing power market [MW]	CG1 residual capacity after balancing power market offers [MW]	CG2 residual capacity after balancing power market offers [MW]	Trades in Elbas [MWh]	Use of DER in balance management [MWh]	Realized power imbalance [MWh]	CG1 allocated control actions [MWh] / [MW]	CG2 allocated control actions [MWh] / [MW]
1	*10.0 (CG1)*	*0.0*	7.2	1.0	0.0	-0.2	*-10.0* *17*	0.0
2	*10.0 (CG1)*	*0.0*	7.4	0.0	0.0	-0.3	*0.0* *7*	0.0
3	*10.0 (CG1)*	*7.0*	7.6	-9.0	0.0	-0.5	*0.0*	0.0
4	*10.0 (CG1)*	*2.0*	7.6	-2.0	0.0	-0.4	*-5.0* *5*	0.0
5	*10.0 (CG1)*	*7.0*	7.7	-2.0	0.0	-0.4	*-10.0* *10*	0.0
6	0.0	*0.0*	4.2	4.0	0.0	-0.1	*0.0*	0.0 4.1
7	0.0	*0.0*	5.3	0.0	0.0	-0.1	*0.0*	0.0
8	0.0	*0.0*	10.4	0.0	0.0	-2.8	*0.0*	0.0
9	0.0	*0.0*	7.3	0.0	-6.0 (CG2)	-0.3	*0.0*	-11.5
10	0.0	*0.0*	7.2	11.0	6.0 (CG2)	-1.3	*0.0*	11.5
11	10.0 (CG2)	*0.0*	1.1	2.0	0.0	1.4	*0.0*	0.0
12	0.0	*0.0*	11.0	0.0	0.0	0.5	*0.0*	0.0
13	10.0 (CG2)	*0.0*	0.5	0.0	0.0	-1.1	*0.0*	0.0
14	0.0	*0.0*	9.9	0.0	0.0	0.1	*0.0*	0.0
15	0.0	*0.0*	9.7	0.0	0.0	-1.1	*0.0*	0.0
16	0.0	*0.0*	9.3	0.0	0.0	0.1	*0.0*	0.0
17	0.0	*0.0*	8.9	0.0	0.0	-0.8	*0.0*	0.0
18	0.0	*0.0*	0.0	0.0	0.0	1.0	*0.0*	-12.5
19	0.0	*0.0*	0.0	1.0	0.0	-0.2	*0.0*	12.5
20	0.0	*0.0*	8.4	0.0	0.0	0.0	*0.0*	0.0
21	0.0	*0.0*	8.1	0.0	0.0	0.2	*0.0*	0.0
22	0.0	*0.0*	7.4	0.0	0.0	-0.2	*0.0*	0.0
23	0.0	*0.0*	7.2	15.0	0.0	-0.2	*15.0*	0.0
24	0.0	0.0	5.6	9.0	0.0	-0.2	*10.0*	0.0

Table 5.8 demonstrates the retailer's central operation close to the time of delivery. The second column presents the offers in the balancing power market. The accepted offers are indicated by red colour. The third and fourth columns of the table show the CG1 and CG2 residual control capacities after the offers, respectively. The fifth column shows the retailer's balancing trades in Elbas. The value for hour 9 is shown with an orange background to demonstrate that the planned trades in Elbas could not be made. The sixth column shows the DER control actions that are allocated to the balance management. The seventh column of the table shows the realized power imbalance of the retailer. The last two columns present the retailer's allocated CG1 and CG2 control actions, except for the control actions that were allocated before the Elspot trades for CG1. If the capacity is allocated to the reserve use in a particular hour, it is indicated by a red underlined value. The primary effects of the allocated DER control actions are presented with a yellow background, and the secondary effects with a light yellow background.

Table 5.8 shows that the retailer has placed 10 MW offers of the CG1 capacity to the balancing power market in hours 1–5, of which the offers for hours 1 and 5 are accepted. It is pointed outs that when a retailer places an offer, the corresponding capacity is preliminarily allocated to the use. The offered capacity remains allocated to the reserve use until the actual use is known. As presented above, if the CG1 capacity is accepted to a reserve use, the retailer allocates the substitute heating load consumption to the last hours of the day, except in the case of the FCR-D use where the estimated impacts to the consumption are assumed to be insignificant. As a result of the accepted balancing power and the FRR-A market offers, the retailer has allocated 15 MWh and 10 MWh substitute heating load consumption to hours 23 and 24, respectively.

At the beginning of the delivery day, the retailer has made successful balancing trades between hours 1 and 5, because only minor imbalances take place. It is noted that the imbalances presented in the table do not include the imbalances resulting from the reserve use of DER during the delivery hour, because the retailer is automatically compensated for the imbalances in the imbalance settlement. When it comes to the reserve use of DER in these hours, 10 MW of CG1 capacity is reserved for the FRR-M use in hours 1 and 5, 5 MW is reserved for the FRR-A use in hour 4, and 7 MW is reserved for the FRC-D use in hour 1 and 2. Right after the delivery, the retailer verifies these reserve uses, and based on this, updates the preliminary allocations of substitute heating load consumptions in hours 23 and 24. For the sake of simplicity, it is assumed that the preliminary allocations match the reserve use, and there is no need to adjust the preliminary allocations.

In hours 6–8, the retailer's physical open position is close to zero before the delivery hours. Therefore, there is no need to make any balancing operations, but in hour 8 the demand forecast inaccuracies result in some imbalance. At these hours, no offers to the balancing market are placed either because of the low residual DER control capacities.

However, 4.1 MW of CG2 capacity is allocated to hour 6 to the FCR-D use as planned, but this does not have a significant impact on the consumption.

In hour 9, the retailer aims at making balancing trades in Elbas, bus is not able to complete the planned trades (at a feasible price). Therefore, the retailer considers an alternative to use the CG2 residual control capacity in hour 9 to minimize the imbalance. To this end, when hour 9 Elbas trading ends, the retailer preliminarily allocates a -6 MWh control action for the CG2 to the hour. This results in an estimated 6 MWh increase in the hour 10 consumption, and thereby calls for corresponding Elbas purchases. The retailer has now about one hour time to make balancing trades for hour 10 before the Elspot trading closes and the delivery of hour 9 starts. Before this, also the final decision has to be made on the implementation of the control action planned for hour 9. Basically this means that if the required balancing trades for hour 10 cannot be made, the retailer has to decide whether to implement the control actions and take the imbalance in hour 10, or not and take imbalance in hour 9. The retailer is able to conclude trades for hour 10 in Elbas, and therefore, makes the decision to implement the planned balancing control action. This decision is also supported by price forecasts and realized Elspot prices, which indicate that hour 9 price is considerably higher than the price for hour 10.

In addition to the above balancing control action, another control action has been allocated to hour 9 in the preliminary planning of balancing operations (stage 2). Because the high Elspot price was reflected to Elbas and made balancing trades impossible in hour 9, the preliminary planning of this balancing operation has been successful. Therefore, the retailer makes the decision to implement the both planned CG2 control actions, which results in an 11.5 MWh decrease in the hour 9 consumption, and the same increase in the hour 10 consumption. Thanks to this, the retailer is able to keep the actual imbalances of both hours 9 and 10 at a low level. Moreover, because the prices in Elspot and Elbas were considerably higher in hour 9 than in hour 10, the applied CG2 control actions produce profits for the retailer. The above description illustrates efficiently how the use of DER can enhance the retailer's ability to manage the imbalance risk, even if the DER control actions have secondary effects, as long as the operation is planned carefully in advance and adjusted dynamically at the time of delivery.

Between hours 11–17, the retailer makes some balancing trades in Elbas, but there is no need for major balancing operations. One reason for the low physical open positions is that the offers placed to the balancing power market of the CG2 capacity to hours 11–13 are not accepted. Had they been accepted, the secondary effects of the control actions would most likely have led to increasing imbalances. The retailer has also been able to forecast the consumption quite accurately, and manage the imbalance risk well during the considered time interval. Furthermore, there were no indications of unusually high or low prices, which would have given incentives for further adjustment of the power balance.

A price spike was indicated in hour 18, as it was presented in section 5.4. Therefore, the retailer allocated CG2 control actions to hour 18 and planned the Elspot trades accordingly. The price spike occurred as forecasted, and the Elspot trades for the hour were made as planned. Therefore, the retailer has no need for balancing operations in hour 18, but only the planned control is completed. In hour 19, the payback effect of the control action takes place. This was also considered previously in the operation plans, and therefore, only a 1 MWh balancing trade is made in hour 19.

At the end of the day, the retailer makes balancing trades in Elbas as planned. The highest volumes are traded in hours 23 and 24 to cover the reallocated substituting heating load consumption of CG1. As a result of the successful balancing trades, accurate consumption forecasts, and appropriate planning of the operation, the imbalance is very low at the end of the day. Other specific operations are not made at the end of the day.

To sum up, the retailer's operations at the delivery day were successful, because no major imbalances materialized. In addition, the retailer operation at the time of the hour 18 price spike was planned well and produced profits. The main reason for this is that the retailer was able to forecast the price spike and plan the DER use accordingly. In addition, the retailer was able to avoid the rather high imbalance in hour 9, although the planned Elbas trades could not be made. By shifting the CG2 loads one hour forward, and by making balancing trades for 10 hour, materialization of the imbalance risk was avoided. The above example illustrates efficiently how the dynamically planned use of DER according to real-time data and forecasts can enhance the retailer's short-term profit optimization.

5.9.3 Summary of delivery and settlement

The retailer operation close to the delivery in the profit-optimization stage 6 is summarized as follows:

1. Use the preliminary operation plan as a guideline for the delivery day operation. However, adjust the operation continuously to match the current operating and market conditions.
2. Update the forecasts continuously and verify the completed operations as soon as possible. Pay special attention to the fast verification of the DER control actions in the reserve use. Use these data as input for planning of the future operation.
3. If a planned trade cannot be made, estimate the need to adjust the operation plan. If balancing trade(s) in Elbas cannot be made as planned, consider alternatives to manage the power balance using residual DER. This may allow to avoid an unprofitable power imbalance, even if the planned Elbas trades could not be made.
4. Consider the interactions between different operations before making decisions. For instance, adjustment of previously planned DER control actions can affect not only the operation in a specific delivery hour, but also the operation in other hours.
5. Take advantage of the past experiences when planning the future operation.

6 Analyses of the economic potential of DER

Implementation of the profit optimization methodology, presented in the previous chapter, requires a number of applications that provide the required input data such as electricity price and consumption forecasts, estimations of the available DER control capacity, and data of control actions taken. Comprehensive testing of the methodology is also challenged by the limited availability of the needed input data, based on which DER control actions in various marketplaces and other operations of the retailer can be modelled accurately enough. Therefore, a practical approach is taken to the testing of the methodology. Based on the proposed short-term profit optimization methodology, an analysis and calculation model is built to enable modular testing of the short-term profit optimization methodology and to analyse the economic potential of DER control actions within the electricity retailer's short-term operation. Similarly as the profit optimization methodology, the analysis and calculation model comprises modules that represent the retailer operation in different stages of the short-term operation, or more precisely, the use of DER in different marketplaces.

This chapter introduces simulations that are performed to test the methodology by using the calculation and analysis model in historical analyses, which produce data of the economic potential of DER in different marketplaces. Historical electricity price and consumption data and some simplifying assumptions are applied to enable practical modelling without tackling the price and consumption forecasting and other modelling complexities. The simulation results are analysed especially from the perspective of the economic potential and risks of the DER control actions. This also includes analysis of the key factors that have an effect on the risks and the profit-making potential. Finally, the applicability of the methodology and the calculation and analysis model is analysed in the light of the results and experiences gathered.

6.1 Economic potential of DER in different marketplaces

The developed calculation and analysis model is first adopted to the historical analyses that produce data of the theoretical economic potential of an example control group's DER control in different marketplaces. For the sake of simplicity and analogy, control group 2 (CG2), which was also used to illustrate the problem formulation in the previous chapter, is taken into consideration. The analysis shows the theoretical profit-making potential, in other words, the economic potential that the control group can provide when it is controlled according to the proposed profit optimization methodology.

The theoretical economic potential provided by the example control group (CG2) DER control is analysed within the examination period of 1 November 2011–30 October 2012. The profit-making potential is simulated based on the real-world data available, that is, historical electricity prices and AMR data of an example customer group. The load control potential, or the control capacity of CG2 available, is modelled as temperature-dependent heating load consumption based on the customer group's hour-resolution

AMR data, by taking the approach introduced in section 4.5.4. The customer group consists of 1388 customers with direct electric heating loads and water heating loads with a 300 l hot-water tank at the maximum. The consumption of these controllable heating loads represents the CG2 control potential available.

The modelling approach and assumptions introduced in Chapter 4 are adopted in the simulations with a few exceptions that are introduced next in brief, and discussed in more detail in the context of the analyses when relevant. To overcome the challenge associated with the relatively small control capacity of the control group, which does not satisfy for instance the 10 MW minimum capacity requirement set by the balancing power market, it is assumed that the customer group is controlled as part of a larger aggregated DER entity. Based on this assumption, it is further assumed that the example control group CG2's control actions can be implemented according to the retailer's profit maximization objective so that the retailer's risk constraints are not violated. In other words, the retailer's risk constraints are released. Furthermore, it is assumed that the end-users' heating load consumption does not vary considerably within an hour, but instead, the control power (MW) indicated by the hourly average consumption (MWh/h) is available at each moment. These assumptions are applied to enable the modelling of DER control actions regardless of challenges resulting from the limited input data available. In other respects, the control actions are simulated by considering the practical aspects. The simulated control actions of CG2 are implemented within the given control constraints, which were introduced in section 4.5.4. These control constraints and other central modelling aspects applied in the simulations are given in Table 6.1.

Table 6.1. Key modelling aspects and control constraints of the simulated CG2 control actions.

	Description	Modelling in the simulations
Available control capacity	Customer group's hourly heating load consumption that can be controlled by the retailer.	Modelled as temperature-dependent heating load consumption. The load control potential available within the examination period varies between 0 and (-) 5.8 MWh/h.
Secondary/ payback effect of control	Disconnection of the control group's loads in hour t results in a payback effect in the following hour t+1.	The duration of the payback effect equals the duration of the primary effect of control (1 h). Payback factor of load control: $\beta = 1$. (Changes in the consumption at the time of primary and secondary (payback) effects of control are in opposite directions but equal in terms of the absolute value of controlled energy.)
Control constraints	Control constraints that are applied to the simulated control actions to make sure that the end-users' comfort or reliability of the retailer operation is not compromised or regulations are not violated.	Maximum control frequency: 5 control actions / day Maximum continuous load disconnection time: 1 h After loads are disconnected in hour t, there is 1h control restraint time, within which the payback effects of control actions take place and new load disconnections cannot be implemented.

The following sections present the above-described simulations that show the theoretical economic potential provided by the control group (CG2) in the day-ahead Elspot market, balancing power market, and the hourly market of frequency containment disturbance reserve. These historical analyses can be described as best-case scenarios in that the economic potential of the example control groups is calculated by optimizing the control actions based on actual historical electricity price and consumption data. This means that the price and demand uncertainties are considered only implicitly in the modelling data. The proposed modelling approach is enabled by the assumption that the retailer is able to offer the capacity to the market so that the optimal control actions are implemented. This also includes the assumption that the offers and use of DER do not considerably affect the retailer's other operations.

Although the applied modelling assumptions may not be realistic in all respects, it is pointed out that the presented historical analyses aim at testing of the proposed profit optimization methodology and the analysis of the theoretical economic potential that the different marketplaces provide. From this perspective, and considering the challenges related to the limited input data available for the modelling, the assumptions can be justified. Furthermore, the practical aspects related to the price uncertainties and determination of the optimal bidding strategy are addressed later in section 6.2, in which another set of simulations are introduced and analysed.

6.1.1 Elspot market

The economic potential of the CG2 load control in the Elspot market is analysed first. The basic idea of the simulation is that the retailer uses the available control capacity of CG2 according to the profit maximization objective and within the given control constraints. Control actions carried out for CG2 result in a decrease in the control group's consumption in hour *t* when the loads are disconnected, and an increase in the consumption of the following hour $t' = t + 1$ when the loads are switched on again and a payback effect takes place. Therefore, the profit maximization objective for CG2 load control actions can be formulated as

$$\mathrm{Max}\left(p_{\mathrm{sell}}(t) * E_{\mathrm{CG2},\Delta}(t) + p_{\mathrm{buy}}(t') * E_{\mathrm{CG2},\Delta}(t')\ \right) \tag{6.1}$$

where

$p_{\mathrm{sell}}(t)$ price at which electricity is sold in hour *t*
$p_{\mathrm{buy}}(t')$ price at which electricity is purchased in hour t'
$E_{\mathrm{CG2},\Delta}(t)$ change in the CG2 consumption in hour t as a result of the applied DER control actions

In this case, the retailer controls CG2 loads in the Elspot markets. When the loads are disconnected in hour *t*, the retailer sells the volume $E_{\mathrm{CG2},\Delta}(t)$ of energy in the Elspot at the area price of Finland. Correspondingly, when the loads are reconnected for the following hour t', the retailer purchases the volume $E_{\mathrm{CG2},\Delta}(t')$ of energy in the Elspot at the area price of Finland to cover the payback effect. In this way, the retailer implements optimal spot price-based controls using the CG2 control capacity available throughout the examination interval. Figure 6.1 shows the economic potential provided by the simulated CG2 control actions in the Elspot market.

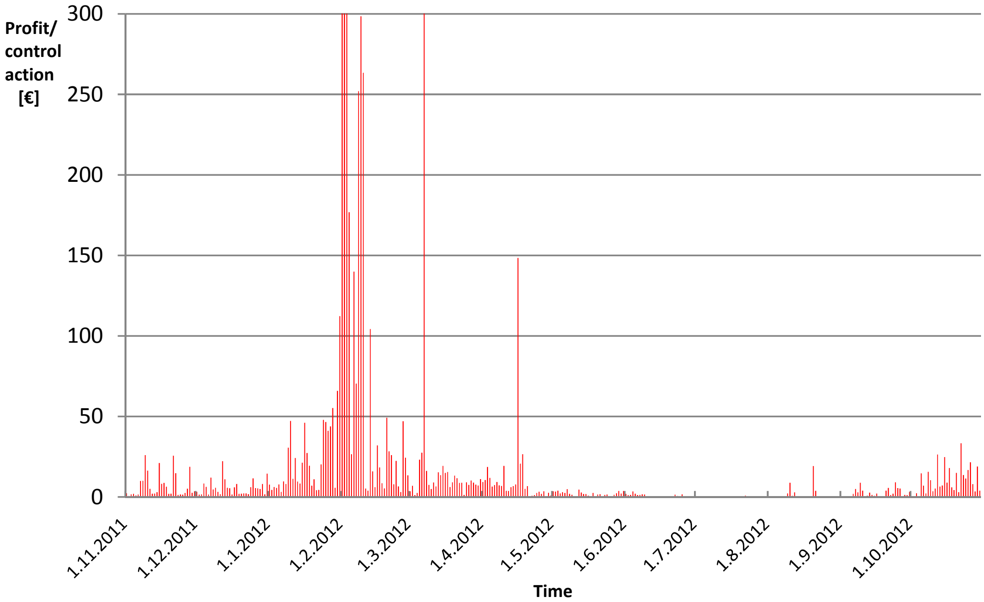

Figure 6.1. Simulation results of the CG2 load control actions in the Elspot market. The maximum value on the vertical axis is limited to 300 €.

The profits from the load control actions within the examination period are presented in the figure by red bars. Because the difference between the lowest and highest profits per control action is large, the maximum value on the vertical axis is limited to 300 € to keep the figure illustrative. The results show that a total of 1330 control actions were carried out during the examination period of 1 November 2011–30 October 2012. This yields a total profit-making potential of approx. 12 500 €. The average profit per control action is over 9 €, and the average profit per controlled end-user is about 9 €. Figure 6.2 shows the simulated profits of the applied control actions, and Figure 6.3 presents the corresponding cumulative profits, when the profits are sorted from the largest to the smallest.

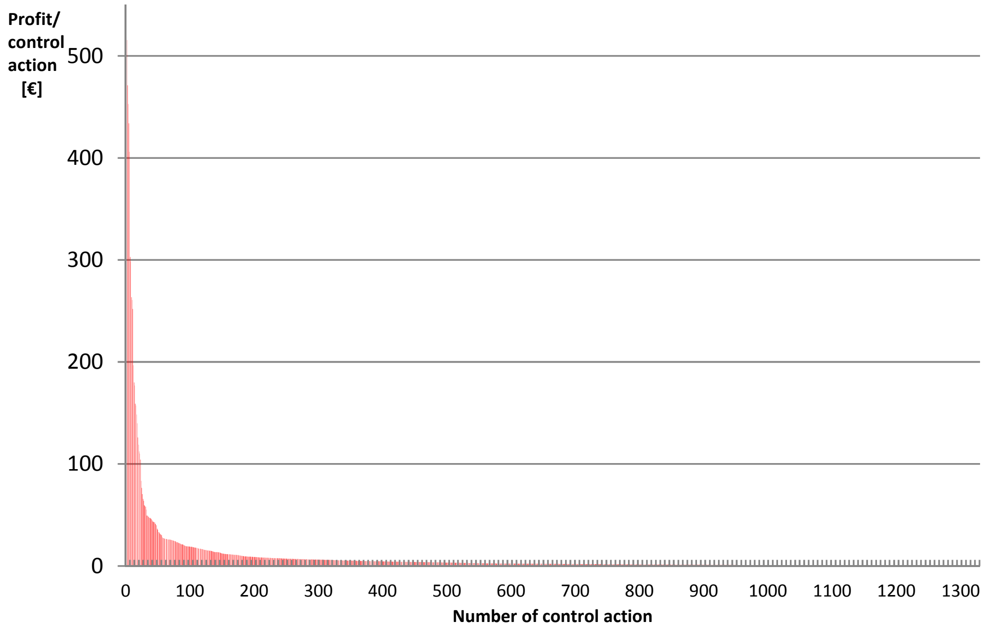

Figure 6.2. Profits of the CG2 hourly control actions in the Elspot market sorted from the largest to the smallest.

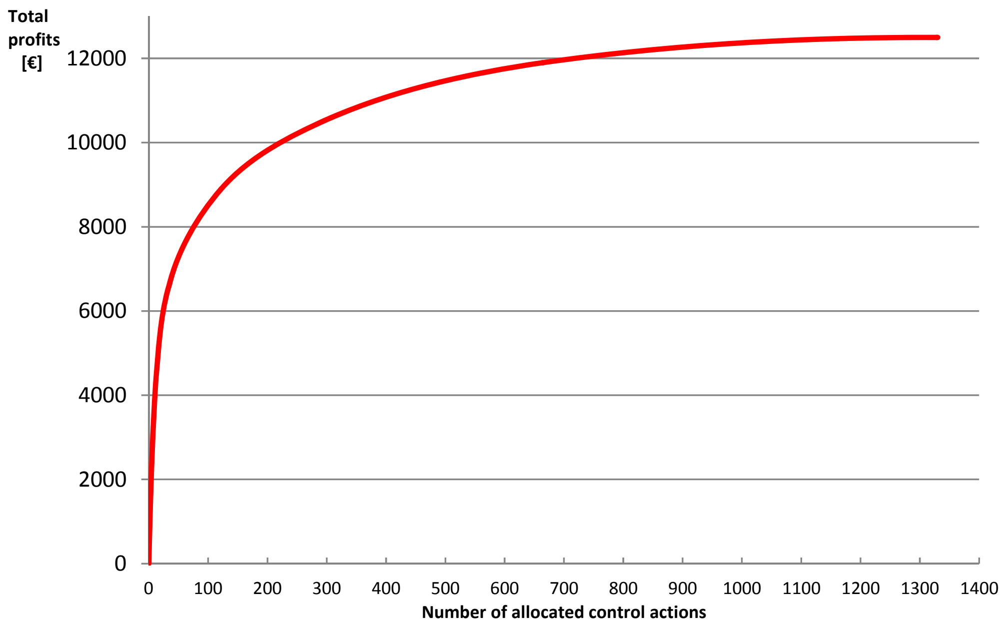

Figure 6.3. Cumulative profits of the CG2 hourly control actions in the Elspot market sorted from the largest to the smallest.

Figure 6.2 shows that there are a rather small number of control actions that produced very high profits, whereas the majority of the applied control actions provided rather modest profits. The highest profit from a single control action is over 518 €, and a total of 23 control actions provided a profit of over 100 €. Figure 6.3, on the other hand, clearly shows that the majority of the total profit-making potential could have been obtained even with a rather low number of correctly allocated control actions. In fact, 28 most profitable control actions, which account for around 2.1 % of the total number of allocated control actions, constituted over half of the total profit-making potential.

6.1.2 Balancing power market

The economic potential of the CG2 load control for up-regulation in the balancing power market is examined next. CG2 control actions are modelled following the same principle and constraints as in the above Elspot market analyses. However, now the regulated energy is sold with the current up-regulation price in the balancing market, and the energy required to cover the payback effect of the CG2 control actions is purchased at current imbalance power price through imbalance settlement. In other words, it is assumed that the retailer is not able to manage the uncompensated imbalances caused by the secondary effects of the CG2 control actions, and therefore, they result in a power imbalance for the retailer. The simulation results are presented in Figure 6.4.

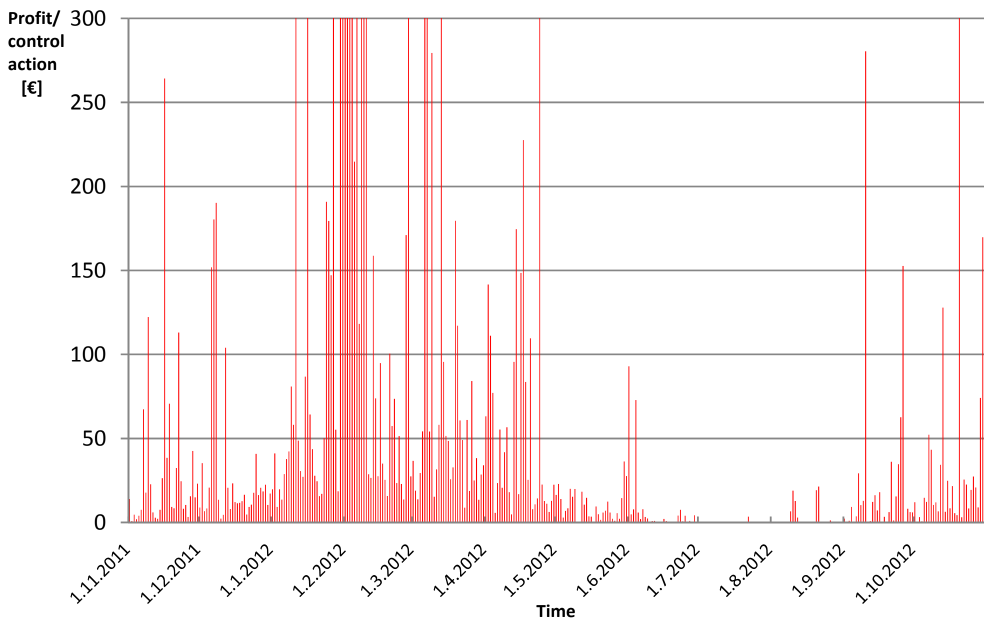

Figure 6.4. Simulation results of the CG2 load control actions in the balancing power market for up-regulation. The maximum value on the vertical axis is limited to 300 €.

The simulation results show that the CG2 control capacity is offered in the balancing power market for up-regulation and applied to use for a total of 1378 times within the examination interval. This yields a total profit of approx. 63 600 €, which equals about a 46 € average profit per control action. The average profit per end-user is also around 46 €. Figure 6.5 shows the simulated profits of the control actions from the largest to the smallest, and Figure 6.6 the corresponding cumulative profit distribution.

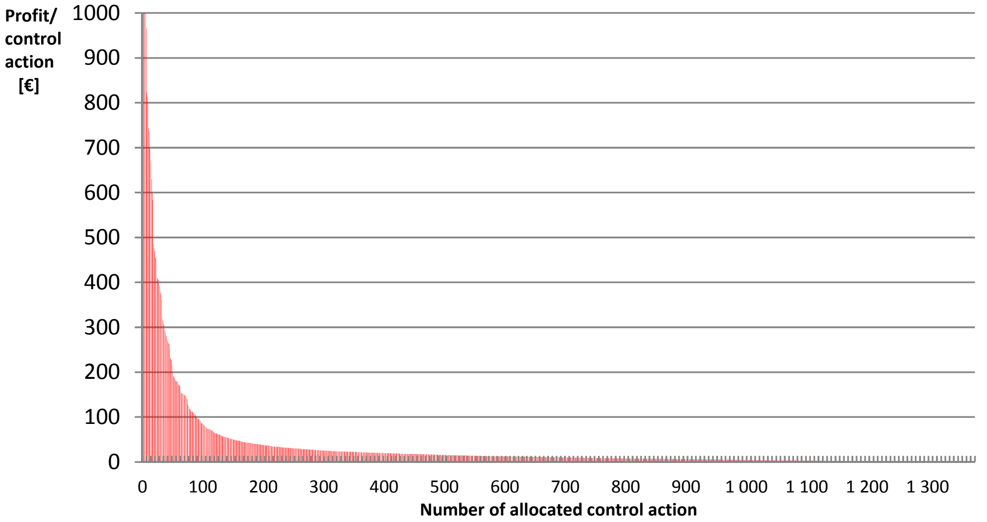

Figure 6.5. Profits of the CG2 control actions in the balancing power market from the largest to the smallest. The maximum value on the vertical axis is limited to 1000 €.

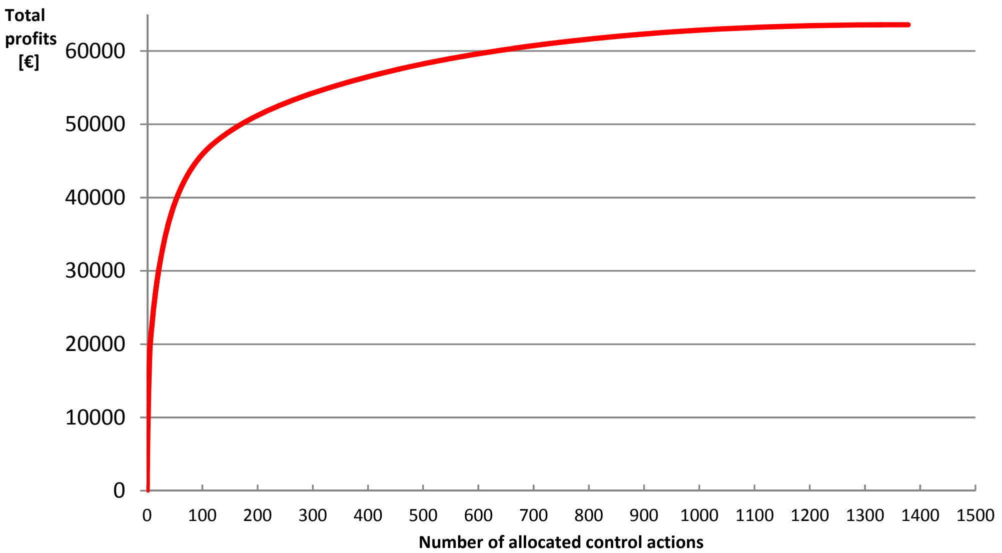

Figure 6.6. Cumulative profits of the CG2 control actions in the balancing power market from the largest to the smallest.

The simulation results show, similarly as in the case of the previous spot market simulation, that a rather small number of the most profitable control actions applied in the balancing market accumulate a majority of the total profits. The highest profit from a single control action is close to 6230 €, whereas five control actions produced an over 1000 € profit, and 23 control actions an over 100 € profit. Moreover, 26 most profitable control actions, which account for around 1.9 % of the total number of allocated control actions, comprised over half of the total profit-making potential.

6.1.3 Frequency Containment Reserve for Disturbances

The theoretical economic potential provided by the CG2 load control in the FCR-D hourly market is presented in this section. Otherwise, the same constraints and control principles as in the above simulations are applied, but the simulation is adjusted to match the operation of the FCR-D. The retailer offers CG2 control capacity (power) to the FCR-D according to its profit maximization objective and within the set control constraints. It is assumed that the optimal offers are made to the market and accepted. In addition, it is assumed that the capacity offered and accepted to the FCR-D market is used only modestly, if at all, to the regulations. Therefore, the impact of control actions applied in the reserve is supposed to be insignificant on the accumulated profits. Instead, only the allocated capacity and hourly market price, according to which the retailer is paid, affect the simulated profits. The simulation results are presented in Figure 6.7.

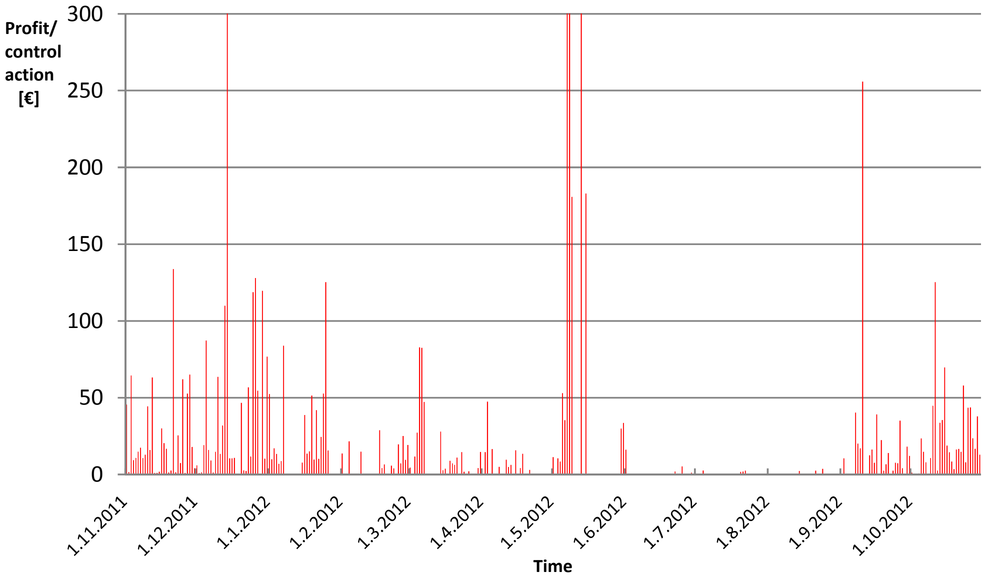

Figure 6.7. Simulation results of the CG2 allocated load control actions in the FCR-D hourly reserve market. The maximum value on the vertical axis is limited to 300 €.

The simulation results show that the CG2 available control capacity is offered in the hourly market and accepted in the FCR-D use a total of 676 times within the examination period. This provides a total estimated economic potential of around 14 800 €. This indicates an approx. 22 € average profit per control action and close to an 11 € profit per end-user. Figure 6.8 shows the simulated profits of the control actions from the largest to the smallest, and Figure 6.9 the corresponding cumulative profit distribution.

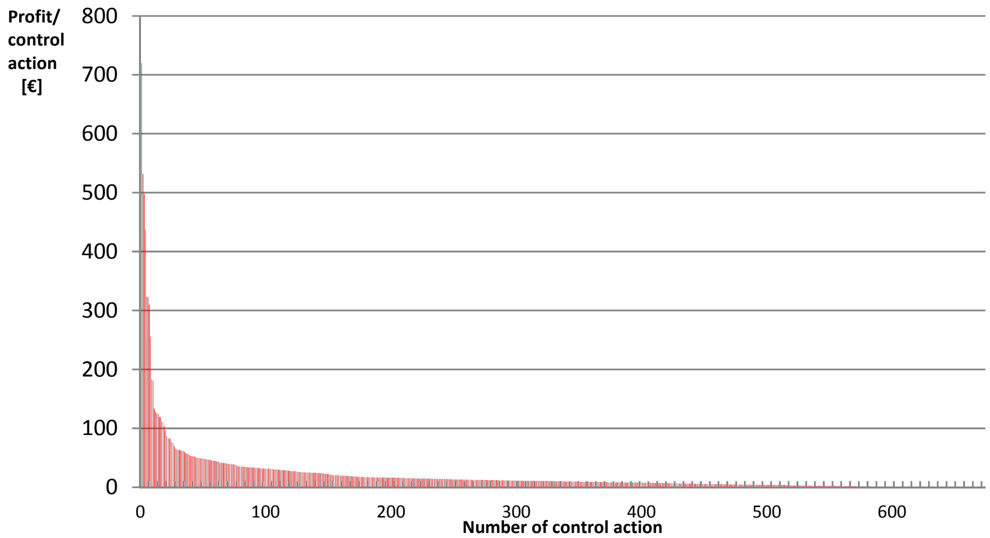

Figure 6.8. Profits of the CG2 allocated control actions (accepted offers) in the FCR-D hourly market from the largest to the smallest.

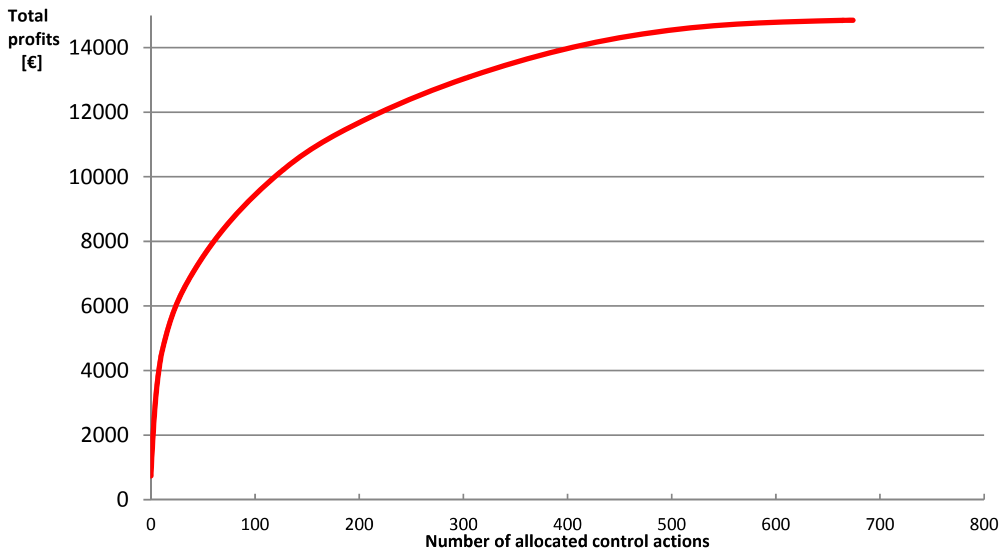

Figure 6.9. Profits of the CG2 allocated control actions (accepted offers) in the FCR-D hourly market from the largest to the smallest.

Figure 6.8 and Figure 6.9 show that the simulated profits from the control actions allocated in the FCR-D market vary considerably, although slightly less than in the case of the previous Elspot and balancing power market simulations. The highest profit of a single control action in FCR-M hourly market is 740 €, and a total of 20 control actions provided over 100 € profit. Around half of the total economic potential is accumulated from 49 most profitable control actions, which corresponds to around 7.2 % of the total number of allocated control actions.

6.1.4 Summary of the simulation results

This section summarizes the results of the first set of simulations, aiming to investigate the economic potential of the CG2 load control in the Elspot market, the balancing power market, and the FCR-D hourly reserve market. The simulation results are summarized in Table 6.2.

Table 6.2. Summary of the simulation results. The theoretical economic potential of the CG2 control in different marketplaces.

Marketplace	Elspot market	Balancing power market	FCR-D hourly market
Total profits [€]	12 500	63 600	14 800
Number of allocated control actions	1 330	1 378	676
Average profit per control action within the examination period [€]	9	46	22
Maximum profit of a single control action during the examination period [€]	518	6 269	740
Number (percentage) of the most profitable control actions required to obtain 50 % of the theoretical maximum profits in the marketplace	28 (2.1 %)	26 (1.9 %)	49 (7.2 %)
Average profit per controlled customer [€]	9	46	11
Relative economic potential of the marketplace compared with the Elspot market	1.0	5.1	1.2
Total profits in relation to the net sales [%]	1.3	6.5	1.5
Total profits in relation to the trading profit [%] with 2,5 €/MWh profit margin	20.2	102.5	23.9

Table 6.2 shows that the theoretical economic potential provided by the Elspot market is low compared with the other marketplaces. The balancing power market yields a superior potential over five times and the FCR-D hourly around 1.2 times as high an economic potential as the Elspot market for the CG2 load control. Table 6.2 also presents the calculated profits in relation to the estimated trading profits and net sales of the retailer within the examination period. The net sales and the trading profits are calculated based on the actual consumption of the customer group (around 25 GWh within the examination period), Elspot prices, and assuming that the retailer’s profit margin from the retail sales is 2.5 €/MWh, around which the current sales margins of spot-price-based retail sales

contracts are. Although the profits obtained from the DER control are quite low compared with the net sales of the customer group, the profits are high compared with the trading profit. Especially the profits produced by the CG2 control in the balancing power market, which are over 100 % of the net profits from the retail sales of the customer group, indicate a remarkable profit-making potential for the DER control. Although the profits provided by the Elspot and FCR-D hourly markets are much lower, around 20 % and 24 % of the net profits, respectively, this also indicates a significant profit-making potential.

It is highlighted that the majority of the total profit-making potential of a marketplace, especially in the balancing power market and the Elspot market, could have been obtained with a rather low number of correctly timed control actions. In the balancing power market and the Elspot market, less than 30 of the over 1300 control actions, and in the FCR-D market, less than 50 of the close to 700 control actions, which brought the highest profits, resulted in over half of the total simulated profits in the marketplace. This is explained by the fact that the control actions at the times of price spikes produced multiple times as high profits as the control actions on average. A closer examination of the simulation results show that in the Elspot and balancing power markets, quite high control capacities were available in January and February, at times when the highest price spikes occurred. In the case of the FCR-D market, however, the control potential available was rather low at the time of the highest prices in May. Consequently, the best profit-making potential in the FCR-D market was exploited much less efficiently than the best profit-making potential of the Elspot and balancing power markets at the beginning of the year.

It is emphasized that although the price spikes yield a high economic potential for the DER control, they can also pose significant risks. This holds especially if the DER control actions have similar secondary effects as in the considered case. The secondary effect of a control action results in an after-peak (payback) to the consumption, which has to be balanced by making additional trades (or allocating new DER control actions). Furthermore, if the secondary effect takes place right after the primary effect of the control, the retailer may not be able make balancing trades in the Elbas market. Instead, the retailer may be forced to establish the power balance by making imbalance power purchases. Again, if the timing of the control is not optimal, and the price spike takes place in an hour when the balancing purchases are made, the retailer may suffer high losses instead of yielding profits. Therefore, the high profit-making potential provided by a DER control action may also indicate high risks associated with the control.

Consequently, although the balancing power market gave the highest profit-making potential in the simulations, it also includes the highest risks for the DER control of the analysed marketplaces. However, the risks related to the DER control in the FCR-D hourly market are considerably lower than the risks in Elspot and, in particular, in the balancing power market. The reason for this is that the use of DER capacity offered and accepted in the FCR-D hourly market is modest in terms of regulated energy. Therefore, the imbalance risk related to the secondary effects of control in the FCR-D is much lower than in the balancing power and Elspot markets.

Based on the above analyses, the consumption and control dynamics of the DER used in a market have a significant effect on the economic potential of the DER control, but also on the retailer’s risks. It is emphasized that especially the secondary effects of DER control actions can considerably affect the profit-making potential and risks related to the use of DER. Nevertheless, the most significant factor from the perspective of the theoretical economic potential of the DER control seems to be the level and volatility of the market prices. Thus, it seems that the high prices and price volatility in a market indicate a high economic potential and risks associated with the DER control, if the DER control results in above-described secondary effects. Next, these aspects are studied in more detail.

Impact of price variations on the economic potential

It is emphasized that market prices may vary considerably between different years in different marketplaces. The impact of market price on the economic potential of the DER control is clearly shown by the analyses presented in (Järventausta et al., 2015), which are made applying the same calculation model and optimization principles as in the above-presented simulations. However, these analyses differ in that the simulations are completed for a 1 MW fixed control capacity assumed to be available around the year. In addition, the applied control constraints differ slightly from the simulations of this study.

The “fixed-capacity” simulations clearly illustrate the impact of market prices on the economic potential of the DER control in a marketplace. In addition, the obtained results can be easily scaled and generalized to different cases. Therefore, similar fixed-capacity simulations as presented (Järventausta et al., 2015) are made to analyse the impact of market prices on the economic potential of the DER control over the recent years. The simulations are completed assuming a fixed 1 MW control capacity, which is available for every hour of the year, and using the same optimization principles and control constraints that were applied previously in “actual-capacity” simulations. The results of these fixed-capacity simulations are presented in Figure 6.10.

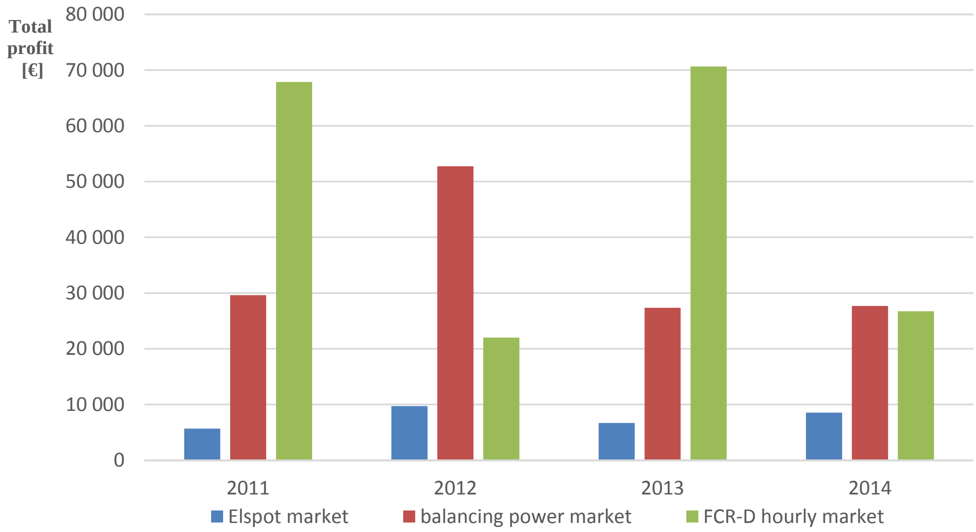

Figure 6.10. Theoretical economic potential provided by a 1 MW DER control capacity in years 2011–2014 in the Elspot, balancing power, and FCR-D hourly markets.

Figure 6.10 shows that in all examined years, the control of a 1 MW capacity in the balancing power market and the FCR-D hourly market yielded at least two times as high theoretical economic potential as in the Elspot market. The relative economic potential between the balancing power and the FCR-D hourly market, on the other hand, varied year by year. Years 2011 and 2013 are rather similar, as in the both years the FCR-D market provided over ten times and the balancing power market close to five times (in 2013 4.1 times) as high an economic potential as the Elspot market. Year 2012, however, differs in that the FCR-D market produced "only" around two times as high an economic potential as Elspot, whereas the balancing power market gave around five times as high an economic potential as the Elspot market. In 2014, both the balancing power and the FCR-D hourly market yielded around three times as high a profit-making potential as the Elspot market.

To sum up, in 2011 and 2013, the FCR-D hourly market provided a superior economic potential for the DER control compared with the other examined marketplaces. In 2012, on the other hand, the balancing power market was clearly the best marketplace in terms of the theoretical economic potential, and the FCR-D the second best. In 2014, the balancing power and the FCR-D hourly markets were almost equal, both providing around three times as high an economic potential as the Elspot market. In the light of these results, the economic potential of the balancing power market and the FCR-D hourly market have been superior over the recent years compared with the Elspot market.

A comparison of the year 2012 fixed-capacity simulation results (Figure 6.10) and the previously presented "actual capacity" simulations results (Table 6.2), the examination interval of which covers mainly the year 2012, shows that the results are quite similar. Some differences between the results can also be expected, because different capacities and slightly different examination intervals are used in the simulations. Still, especially the relative but also absolute economic potentials of the examined marketplaces are rather similar in both simulations. The results of both simulations show that in 2012 the balancing power market provided clearly the highest economic potential, which is explained mainly by the high price spikes that occurred in January and February. The FCR-D hourly market also offered a considerably high profit-making potential, especially in May, again, as a result of the price spikes. The lower relative economic potential of the FCR-D hourly market in the actual capacity simulations can largely be explained by the fact that there were low control capacities available at the time of price spikes in May, as discussed above. This emphasizes that an adequate control potential and correct allocation of control actions are required to exploit the profit-making potential provided by a market. On the other hand, the similarity of the both simulation results, regardless of the different control capacities used in the simulation, indicates that the economic potential of the DER control depends essentially on the market prices.

A closer examination of the fixed-capacity simulations shows that some similarities can be detected in the typical price profiles of different markets. Usually, the highest prices in the FCR-D hourly market seem to occur in spring and autumn. Especially in years 2011 and 2013, as presented also in (Järventausta et al., 2015), the prices were particularly high in the FCR-D hourly market in spring and autumn. This is also the main reason for the high profit-making potential of the DER control of the FCR-D hourly market in these years. A probable reason for price spikes, especially those occurring in May, might be (spring) flooding. This may have prevented the normal use of hydropower capacity for regulation, and resulted in the scarcity of capacity in the market thereby increasing the prices. In the Elspot and balancing power markets, on the other hand, the highest prices seem to take place most commonly in the wintertime. Cold weather conditions, especially combined with the maintenance or malfunctioning of large production units and/or transmission capacity, and other similar events, are probable explanations for the wintertime price spikes. From a practical point of view, consideration of these types of factors, which can explain and give indication of price spikes, can assist the retailer to better exploit the theoretical economic potential of the DER use, as will be discussed next.

Exploitation of the theoretical economic potential

Based on the above analyses, the economic potential of the DER control between the marketplaces may vary year by year. Nevertheless, the balancing power markets and the FCR-D hourly markets seem to constantly produce a higher economic potential than the Elspot market. Still, it has to be emphasized that the above analyses do not consider in detail any demand and price uncertainties, challenges in the determination of the bidding strategy that enables the exploitation of the profit-making potential, or risks related to the secondary effects of the DER control. Instead, the simulation results demonstrate a theoretical economic potential, the exploitation of which can be challenging in practice. On the other hand, the control constraints applied to the above simulations are defined to make sure that the reliability of the operation or the customers' comfort is not compromised in any circumstances, extreme operating conditions excluded. Therefore, the constraints may include some extra safety margins, which decreases the calculated economic potential. For instance, adjustment of the control constraints based on the current operating conditions such as outdoor temperature could enable a more optimal use of the control capacity available.

From the practical point of view, the calculated theoretical economic potential is probably easiest to achieve in the Elspot market. This is because the Elspot prices can typically be forecasted more accurately than other market prices, and the bidding process of Elspot makes it possible to place offers that comprise multiple price and volume intervals. Moreover, the retailer can also allocate DER control actions based on the realized Elspot prices to take advantage of the price fluctuation, although this may result in a need for balancing trades.

The theoretical profit-making potential provided by the balancing market can be more challenging to exploit than the potential of the Elspot market. This is the case particularly if the secondary effects of the DER control actions result in uncompensated power imbalances that pose risks for the retailer. In addition, determination of a bidding strategy that allows to exploit the emerging profit-making opportunities is not a trivial task. Nevertheless, even if the retailer is able to manage the major risks and exploit the most significant profit-making opportunities, which are generally found at the times of price spikes, the balancing power market can yield superior profits for the DER control compared with the Elspot market.

As discussed above, although the actual capacity simulation results of Table 6.2 indicated that the FCR-D hourly market yields only a slightly higher economic potential than the Elspot market, a high profit-making potential was found at the times of price spikes in May, which, however, could not be used efficiently because there was only minor, if any, control capacity available. Further, the fixed-capacity simulation results show that the FCR-D hourly market can yield a superior profit-making potential for the DER control. For instance, in 2011 and 2013, the control of a 1 MW example DER capacity in the FCR-D market produced over ten times as high simulated profits as its control in the Elspot market. In addition, the risks associated with the secondary effects of the DER control do not pose such a high risk in the FCR-D market as in many other marketplaces. This is because the use of the reserve capacity in the FCR-D is typically minor in terms of the regulated energy. Consequently, the FCR-D hourly market is a very attractive alternative for the use of DER, as it can offer a very high profit-making potential, and the risks involved with use of DER are considerably low compared with many other marketplaces. Still, especially the implementation of a bidding strategy that enables the retailer to exploit the theoretical economic potential can pose challenges of its own.

Although the optimal use of DER is challenged by a number of factors, it can considerably improve the profitability of the retail business, if the retailer is able to exploit at least part of the total theoretical economic potential of the DER use. Furthermore, a majority of the yearly theoretical economic potential can be exploited even with a rather low number of correctly-allocated control actions. Consideration of a typical price profile and the profit-making potential of a market and factors that indicate high prices can assist the retailer to exploit the best profit-making opportunities available. For instance, the FCR-D hourly market seems to offer the highest profit-making potential in spring and autumn, whereas the Elspot and balancing power markets seem to provide the best profit-making opportunities usually in the wintertime. By considering this, and focusing offers from the DER capacity available on the market where the highest profit-making potential is estimated to be found, the retailer may be able exploit the theoretical economic potential offered by the DER control more efficiently. In the best case, the use of DER in different marketplaces based on this principle can yield even higher profits than the above simulations indicated in any single marketplaces. Still, the optimal use of DER is also challenged, for instance, by issues related to the determination of a bidding strategy that enables the retailer to use the theoretical economic potential, which is addressed next.

6.2 Impact of the bidding strategy

This section presents simulations that address practical issues involved in the determination of the bidding strategy and the uncertainty of electricity prices, which were not considered in detail in the above analyses. The proposed short-term profit optimization methodology is tested in the following simulations at a more practical level than in the previous simulations. Mainly the same modelling constraints and assumptions as in the previous simulations are applied, but the simulation principle is determined to match the actual operation of the balancing power market. The simulation results show how the profits from the CG2 control actions in the balancing power market depend on the applied bidding strategy, or more precisely, from the placed offer price. Based on the simulation results, the profit-making potential and the risks associated with the secondary effects of the DER control in the balancing power market are analysed. This also gives answers to the question whether the proposed profit optimization methodology and the applied modelling approach are feasible to the modelling of the retailer's short-term operations. In addition, by considering the previous simulation results, it can be estimated how close to each other the theoretical economic potential and the profit-making potential provided by simplistic bidding strategies are.

A set of simulations were implemented to analyse how the offer price set by the retailer affects the profits from the use of the CG2 control capacity for up-regulation in the balancing power market. The same examination interval, control constraints, and input data are used as in the balancing power market simulations in section 6.1.2. However, the control actions are not optimized in terms of economic potential. Instead, the simulations are based on the idea that the retailer offers available load control capacity to the balancing market at a fixed price, which is the same for every hour of the examination period. It is assumed that the retailer obtains information of the accepted offers at the beginning of the delivery hour. If the offer is not accepted, the bid for the following hour is placed if the constraint of five control actions per day is not violated. If the offer is accepted, the bid for the following hour cannot be placed because of the 1 h control restraint time. In the case of an accepted offer, the CG2 whole capacity is used for the regulation. This results in a payback effect at the following hour, which, again, results in a power imbalance. It is assumed that the retailer cannot manage this, for instance by making Elbas trades, but instead, buys consumption imbalance power at the current price in the imbalance settlement to establish the power balance.

The proposed “fixed bid price for every hour” is probably the simplest possible bidding strategy that a retailer can apply, and probably quite far from the optimal bidding strategy. However, for the illustration and testing of the proposed calculation model and methodology, the applied modelling approach is effective and simple enough. The results of the simulations are illustrated in Figure 6.11.

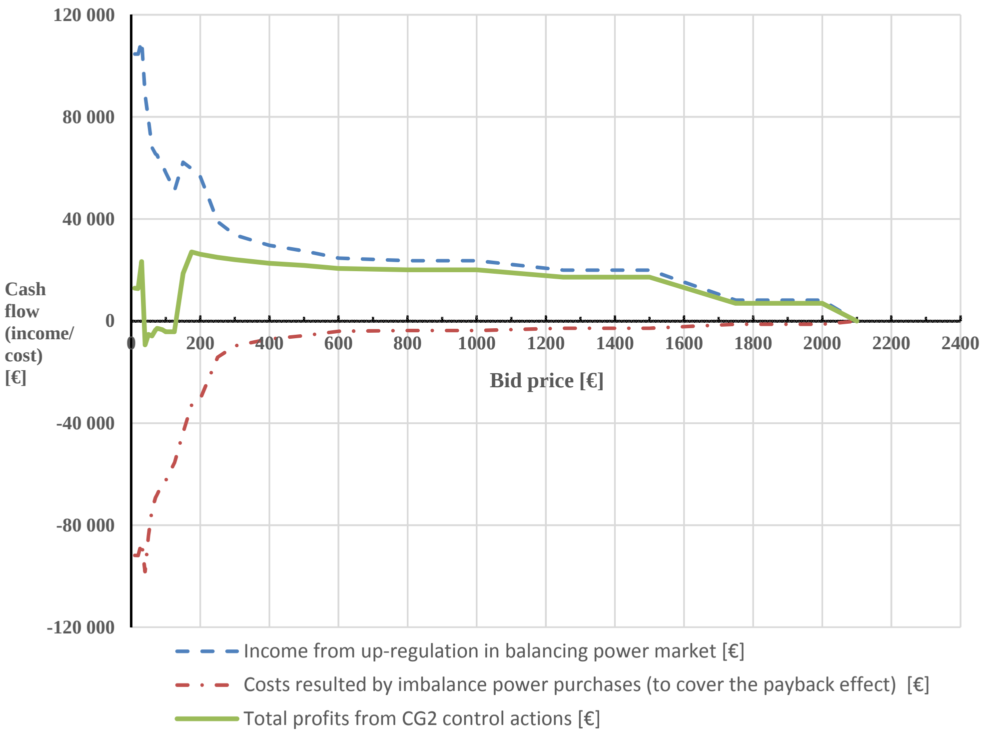

Figure 6.11. Simulation results. The impact of the bid price on the retailer’s profits.

The simulation results show that the incomes produced by the up-regulation and the imbalance power purchase costs resulting from the payback effect of the control decrease if the bid price increases, with some exceptions. This trend is explained by the fact that the number of accepted offers and the following control actions increase if the bid price decreases. However, the bid price levels between of 30 and 150 €/MWh make an exception to this trend in that the sales income is higher than at the next lower bid price level. This can be largely explained by the fact that the timing of the control actions is affected not only by the placed bid price but also by the control constraints. For instance, the control implemented in hour *t* prevents the implementation of the control in hour *t+1*, even if this was a more profitable alternative.

The highest total profits, a total of 27 000 €, give a bid price of 175 €/MWh. In general, the total profits vary considerably under 150 €/MWh bid prices. When the bid price is 150 €/MWh or higher, the profits are quite stable, 20 000 € or more, until the bid price exceeds 1000 €/MWh. Although the profits at the highest bid prices decrease, the total profit per control action is high. For instance at the bid prices of 800 and 1000 €/MWh, a single control action produces 2500 € profit on average. It is emphasized that the bid prices between 50 and 125 €/MWh yield negative profits, or in other words, losses for the retailer. This is explained by the fact that the imbalance power purchases completed to cover the imbalances resulting from the payback effect of the CG2 control actions produce higher costs than the incomes produced by the up-regulation. This means that the risk of the uncompensated imbalances materializes, as illustrated in Figure 6.12.

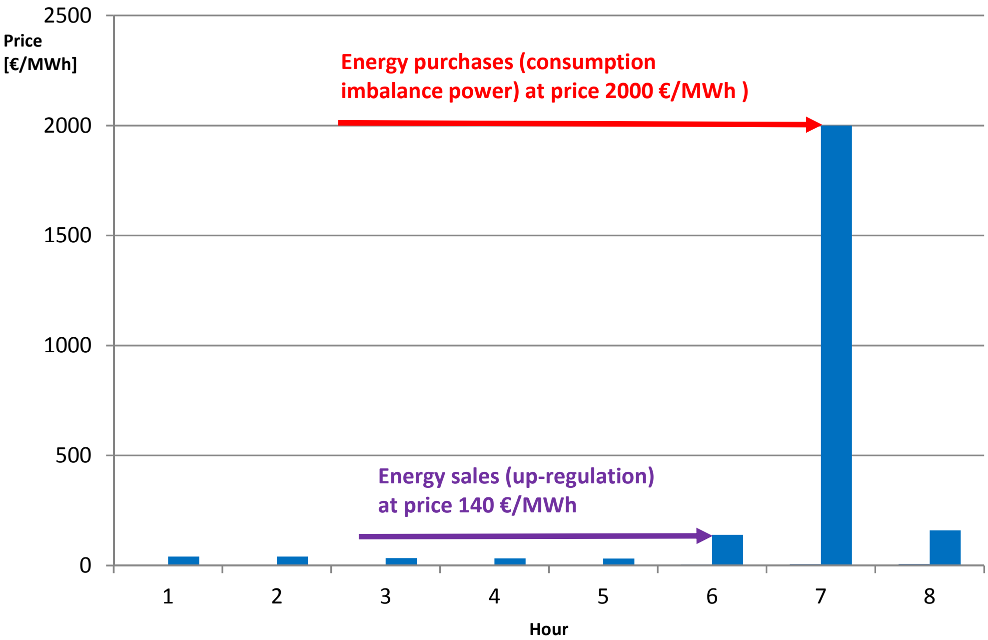

Figure 6.12. Risk of the uncompensated power imbalance resulting from the payback effect of the CG2 control in the balancing power market.

Figure 6.12 shows an operating scenario taking place in the simulations. The retailer has offered the CG2 capacity for up-regulation in the balancing market at the price of 100 €/MWh in hour 6. The offer is accepted and leads to the CG2 load disconnection, and the retailer sells the controlled energy in the balancing power market at the price of 140 €/MWh in hour 6. After the end of the regulation, the loads are reconnected to hour 7.

This results in a payback effect that increases the retailer's consumption. In order to compensate for the resulting power imbalance in hour 7, the retailer purchases imbalance power in hour 8 at the current consumption imbalance price of 2000 €/MWh. Consequently, the risk of uncompensated imbalances materializes, because the retailer purchases energy at a higher price (2000 €/MWh) in the imbalance settlements to cover the payback than sells energy at the time of up-regulation (at price 140 €/MWh) in the balancing power market. As a result of this, the retailer suffers a 1860 €/MWh loss from the applied CG2 control actions. The described operating situation may be a rather extreme example of the risks involved in the secondary effect of DER control actions, but shows clearly how significant risks may result from the secondary effects that cannot be adequately managed. It is also pointed out that within the one-year examination period under study, eight at least 1000 €/MWh price spikes occurred. This produced very high risks, but also high profit-making opportunities for the retailer, which also explains the high variation in the profits at different bid prices.

The simulation results indicate that the bid price has a significant impact on the retailer's risks. In addition, it is pointed out that at low bid prices, the number of control actions increases, which also increases the probability that the risk of uncompensated imbalance resulted by secondary effects of control actions materializes. Especially at low bid prices, also the control constraints have a considerable effect on the timing of control actions.

The simulation results indicate that at high bid prices, the risk of uncompensated imbalance decreases, because the retailer receives profit from all bid prices over 150 €/MWh (until the bid price exceeds 2000 €/MWh and no offers are accepted). This is explained by the fact that when the bid price increases, the average income obtained from the control action increases and compensates for the risk caused by the payback effect of the control. In addition, at high bid prices, the number of control actions decreases, and therefore, the control constraints more seldom prevent from taking advantage of the best emerging profit-making opportunities. Consequently, a high bid price reduces the retailer's risk associated with the secondary effects of the DER control, and can thus yield higher profits than a very low bid price. Still, it is emphasized that also too high a bid price seems to reduce the total profits, because only a very few offers are accepted.

The simulation results and analyses indicate that the secondary effects of the DER control can result in substantial risks for the retailer. These risks can be managed, at least to a great degree, by defining an appropriate bidding strategy, which in this case is to place a high enough bid price. If the control actions do not result in secondary effects, or they can be managed for instance by making Elbas trades, alternative bidding strategies should be considered. In that case, slightly lower bid prices could be more optimal, because they would result in more control actions and could thus increase the incomes. Still, the bid price has to be high enough, because too low a bid price can lead to control actions that bring only modest profits and prevent more profitable control actions.

To sum up, in the example case, the retailer's bidding strategy has a very high impact on the profits from the DER control. It is emphasized that the correct timing of the control actions is crucial. Therefore, the retailer has to plan a bidding strategy that enables the management of the risk related to uncompensated imbalances. This holds especially if the control actions result in secondary effects, which expose the retailer to a high imbalance risk. By comparing the above simulation results with those presented in the previous section (actual capacity simulations), it can be seen that the theoretical economic potential of the load control was around 63600 € in this case, whereas the bid prices over 150 €/MWh but under 1000 € MWH produced constantly over 20 000 € profits. Thus, even by taking a very simplistic bidding strategy, a considerable proportion of the theoretical profit-making potential could have been exploited. Moreover, even the simplistic high-price bidding strategies in the balancing market yielded much higher profits than the theoretical maximum profit-making potential in Elspot (around 12 500 €).

6.3 Summary and conclusions of the economic potential analyses

An analysis and calculation model was built to test the proposed short-term profit optimization methodology and to study the economic potential and risks involved in the use of DER in the electricity retailer's profit optimization. Because of the limited input data, the methodology was tested in a modular manner by completing historical analyses of the economic potential provided by an example control group in different marketplaces. Basically the same modular approach that was used in the problem formulation was applied to the testing of the methodology. In addition, some modelling assumptions were applied to overcome the practical challenges. The main simplifications to the analyses are the use of historic data as the input, the release of the retailer's risk constraints, and market-specific minimum capacity requirements.

The analyses presented of the theoretical economic potential (Table 6.2) show that the profit-making potential provided by the CG2 control within the one-year examination period is over five times as high in the balancing market and around 1.2 times as high in the FCR-D hourly market as in the Elspot market. In order to examine the theoretical economic potential in different examination periods and analyse the impact of market prices on it, additional fixed-capacity analyses were made. The same calculation model and control constraints were used as in the previous simulations, but a fixed 1 MW control capacity that is available around the year was assumed instead. Based on the results of these analyses it was concluded that in year 2012, the relative economic potential of the balancing power market was high, whereas the potential of the FCR-D hourly reserve market was low compared with the years 2011 and 2013. In 2011 and 2013, in similar simulations, the FCR-D yielded an over ten times as high economic potential as Elspot, whereas the balancing market produced an around five times as high economic potential. In 2014, both the FCR-D and the balancing power market provided around three times as high an economic potential as the Elspot market. Consequently, the reserve markets seem to yield a superior profit-making potential compared with the Elspot market, although the potential can vary significantly between the marketplaces in different years.

It was also concluded that the majority of the yearly theoretical economic potential produced by the DER control in a market could be typically obtained by a low number of correctly allocated control actions. Fewer than 30 of the most post profitable control actions in the Elspot and the balancing power market, and fewer than 50 control actions in the FCR-D hourly market, provided over half of the yearly total profit-making potential. This also shows that at the times of price spikes, control actions can easily bring a multiple times higher economic potential than on average. It was also noted that a high profit-making potential offered by price spikes can imply high risks, especially if the DER control action has secondary effects that can result in (uncompensated) imbalances. This aspect was analysed in more detail in the second set of simulations.

The second set of simulations addressed the practical issues related to the determination of the bidding strategy and risks related to the price uncertainties and the secondary effects of the DER control actions. The simulation results show that even a simplistic high-price bidding strategy applied in the balancing market can yield considerably higher profits than the Elspot market for the DER control. However, it was also found that the risks associated with the secondary effects of the DER control actions pose serious risks for the retailer. Therefore, the allocation of the DER capacity, in particular in the reserve markets where the implemented control actions are difficult to forecast, requires careful planning of the bidding strategy and the management of risks involved in the DER control actions. The results indicate that by placing a high enough bid price, the retailer can avoid, at least to a certain degree, the risks associated with the secondary effects of DER control.

To sum up, the simulation results clearly indicate that the use of the DER capacity should be focused rather on reserve markets than the Elspot market. In addition, special attention has to be paid to the risks related to the secondary effects of the DER control actions and uncompensated imbalance. In the worst case, materialization of these risks can result in high losses for the retailer even in a short period of time. Therefore, it is advisable to set a high enough bid price, although this can limit the profits. Still, the high bid price reduces the risks and enables exploiting the highest profit-making opportunities that are generally found at the times of price spikes. Ultimately, the current level of market prices define the optimal bid price in each case. Therefore, the use of DER cannot be planned mechanically, but dynamic adjustment of the operation based on the changing market and operating conditions is required.

The analyses of the economic potential of DER showed the feasibility of the proposed short-term profit optimization methodology and the modelling method in the cases under study. The proposed short-term profit optimization methodology increased the retailer's profits in all simulations. However, when simplistic bidding strategies were tested without optimization, the importance of careful risk management was highlighted. Further, it was shown that a retailer is exposed to high risks, if it offers capacity to the market without careful consideration of the secondary effects that can result in unfavourable power imbalances. This is because the retailer may be forced to buy imbalance power at a very high price, which results in costs that are higher than the profits obtained from the offered capacity. However, by setting a high enough bid price, the exposure to this risk can be considerably reduced. Moreover, even if the retailer is able to take advantage of even some tens of the most profitable high-price hours efficiently, the retailer can exploit a majority of the total economic potential of a market.

Finally, it is emphasized that the historical analyses show the economic potential provided by the DER in the cases under study. In practice, the economic potential of DER control actions may vary significantly, depending on the current market prices, DER control potential available, and consumption and control dynamics of the DER. Therefore, future research could include more analyses with different examination intervals and on different types of DER. By emphasizing the practical issues related to the comprehensive testing of the model, set for instance by limited resources and input data available, and the extensive workload that the comprehensive testing of the proposed profit optimization model would require, the modular testing was deemed successful. The historical analyses showed a systematic increase in the retailer's profits when the DER and the profit optimization methodology were applied. This confirms that the proposed profit optimization approach can enhance the retailer's short-term profit optimization.

7 Conclusion

The transition to the future smart grid environment is changing the operating environment. This poses various risks, but also provides opportunities to the electricity market players, including the retailers. The increasing penetration of small-scale distributed generation, consisting mainly of intermittent renewables, poses substantial risks to the electricity retailers, for instance in the form of increasing fluctuations in the electricity demand and price. Integration of distributed energy resources (DER), especially energy storages and controllable loads give new tools for the retailer's profit maximization and risk management. In order to exploit the opportunities and hedge against the risks, the retailers have to adjust their operation models to match the specific characteristics of the emerging smart grid environment, in which the active use of DER plays an increasingly important role. To this end, a methodology has been developed to enable the electricity retailers to use DER efficiently in their short-term profit optimization.

The main contributions of this doctoral dissertation are found in the analysis and development of the model that allows an electricity retailer, or other corresponding market-based operator such as an aggregator to benefit from profit-making opportunities provided by the use of DER in different marketplaces, but also to manage the major risks involved in the active use of DER. The scientific contributions of this work are

- Methodology for comprehensive modelling of an electricity retailer's short-term profit optimization.
- Methods to model the use of DER and manage the risks in the retailer's short-time operation.
- Analysis of the economic potential of the DER use, which reveals that DER control actions in balancing power market produce a high profit-making potential, but can also involve high risks, if they generate secondary effects that the retailer is not compensated for and that cannot be managed adequately.
- Analysis of the key factors that have an effect on the profits of the DER use. The results emphasize the efficient exploitation of the highest-price hours, of which rather a few can constitute a majority of the yearly profit-making potential of a market, and the management of risks related to them.

To the best of the author's knowledge, for the time being, there is no other as comprehensive model available for the use of DER in the electricity profit optimization as the one presented in this doctoral dissertation. The proposed model comprises the use of DER as part of the retailer's short-term operation in various short-term markets including day-ahead, intraday, and reserve markets. Although the proposed profit optimization approach is designed for the Nordic electricity markets and the Finnish reserve markets, it can be applied, at least to a certain degree, also to other markets of the same type. However, it is emphasized that the divergent operating and market environments call for a methodology that is developed considering the specific characteristics of each operating and market environment.

The decision-making framework developed in this doctoral dissertation facilitates the recognition of the key aspects in the planning of a retailer's short-term profit optimization, and especially the use of DER in profit optimization. The methodology introduced in this dissertation assists in evaluating how different factors and decisions made by the retailer affect the short-term operation in different marketplaces. The introduced calculation and analyses can be used to address the profit-making potential provided by the use of different types of DER in various marketplaces.

The main findings of this doctoral dissertation can be described as follows:

- The retailer's short-term profit optimization includes multiple decision-making problems that are characterized by the uncertainty of the main decision-making variables, that is, the electricity market prices and demands. Therefore, complete automation of the profit optimization is not feasible. Instead, the decision-making and optimization has to be developed continuously by considering changes in the operating and market conditions and by learning from past experiences.

- There is no single superior general strategy for the retailer's short-term profit optimization. An optimal operation plan in each case has to be defined by taking into account the risks involved in electricity price and demand uncertainties, formerly established hedging, and future trading opportunities available. Special attention has to be paid to the careful planning of DER control actions; in particular, if they have secondary effects such as a payback effect of load control that can result in imbalances also outside the delivery hour in question. If these are not considered in advance, and cannot be managed appropriately for instance by making balancing trades, they can lead to unfavourable imbalance power trades and thereby substantial costs for the retailer.

- The characteristics of the applied DER, requirements of various marketplaces, and limitations set by the end-users have to be analysed in detail in order to define the consumption and control dynamics of DER. Knowledge of these aspects is required for the planning of DER control actions so that the most significant risks and profit-making opportunities of DER control actions are taken into account.

- The retailer's short-term operation plan has to be updated according to the changing market and operating conditions in order to benefit from the arising profit-making opportunities and manage the emerging risks. This requires expedient measurements or other corresponding means that enable fast and reliable verification/estimation of the impacts of DER control actions on the retailer's load profile. In addition, forecasting applications that produce input data for planning of future DER control actions are needed. In particular, sophisticated price forecasting applications, which are able to forecast not only normal-range prices but also the probability of a price spike occurrence, can help the retailer to avoid major risks and exploit the profit-making opportunities of price spikes.

- The importance of an appropriate bidding strategy is emphasized in the context of DER use in the retailer's short-term profit optimization. In order to exploit the best emerging profit-making opportunities and manage major risks, offers of available DER capacity in the markets have to be planned by taking into account various aspects. Especially the sequential operation of the markets, risk associated with the secondary effects of DER control actions, and characteristics of markets such as applied pricing mechanisms and typical use of the DER capacity have to be considered.

- A guideline for placing DER (sales) offers is to first consider the risks involved in the DER control actions and their secondary effects. In general, the higher the associated risks are, the higher the bid price should be to compensate for the risks. In addition, by offering the available DER capacity with a high enough price, the best emerging profit-making opportunities in different marketplaces can be better taken advantage of. This is explained by the fact that the retailer can offer the same capacity sequentially in different marketplaces until the offer is accepted, and the DER capacity is allocated to the particular use. In addition, the high enough offer price reduces the probability that the capacity is used in the first marketplace(s), even if the following marketplace(s) provides higher profits. Nevertheless, even if the capacity is not accepted in any market as a result of a high offer price, it can be used for the balance management. Furthermore, it can also be more profitable to preserve the capacity available in later use than use it to yield low profits. This is, especially, if the use of DER includes high risks and can lead to losing of better (later) profit-making opportunities.

- Analyses of the economic potential of DER control show that the profit-making potential between the marketplaces and different periods of time can vary considerably. Nevertheless, the reserve markets seem to provide a multiple times higher economic potential for the use of DER than the day-ahead (Elspot) market. The analyses also indicate that a majority of the yearly economic potential of a market is provided by some tens of hours, in which the prices (or price volatility) are especially high. This further means that the retailer can exploit a majority of the total economic potential of a market even with a rather low number of correctly allocated control actions. Although a high profit-making potential can indicate high risks, they can differ significantly depending on the type of DER used and the marketplace in question. This highlights the importance of careful planning of the DER use considering the specific features of the marketplace and the characteristics of DER in question.

- The FCR-D (Frequency Containment Reserve for Disturbances) hourly reserve market is a very attractive marketplace for the use of various DER. It offers a high economic potential for DER control actions. Further, the risks associated with the secondary effects of DER control actions are rather low, because the use of the reserved capacity is typically minor in terms of the volume of controlled energy.

- The use of DER in the balancing power market can bring a high economic potential, but can also result in extensive risks, especially if the secondary effects of the implemented control actions take place at the hour following the delivery. This is because the retailer is not compensated for the resulting power imbalances that take place outside the delivery hour in the imbalance settlement, and their management may not be possible otherwise (e.g. making Elbas trades) either.

- The retailer's balance management is an important part of the comprehensive profit optimization. Even minor DER capacities that cannot be offered for instance in the balancing power market as a result of the minimum capacity limits can be used in the balance management. A guideline on the balance management is to aim at minimizing the power imbalance, in particular, if future prices involve high uncertainties. Nevertheless, occasional management of power balance, for instance to be slightly positive (surplus in procurements) at the time of an indicated price spike, can be preferred in order to minimize the risk of unprofitable imbalances, and exploit profitable imbalance power trading opportunities instead. However, high power imbalances and a systematic use of open deliveries have to be avoided. In addition, efficient balance management using DER requires accurate and real-time enough forecasts and/or measurements.

The proposed methodology and modelling approach were designed to enable comprehensive modelling of the retailer's short-term profit optimization. It may not give an answer to the question which is the best operation or bidding plan in a specific case. Instead, it provides means to derive an advantageous short-term operation plan that takes into account the key profit-making opportunities and risks, as far as this is possible considering the inherent uncertainty of electricity price and demand, and allows the retailer to adjust its operation based on the current operating and market conditions.

The retailer's short-term profit optimization is a complex and multi-stage process including decision-making based on electricity price and consumption forecasts, which may involve significant uncertainties. Therefore, finding a global optimal solution to the problem is virtually impossible. Consequently, the global optimization problem was approached in this doctoral dissertation by dividing it first into sub-problems, which can be handled and solved more easily. By considering the fact that even an optimal solution of each sub-problem does not guarantee a global optimal solution, a modular modelling approach was developed by also incorporating a systemic approach into the study. The consideration of the systemic approach makes it possible to identify the main interactions between different stages of operation, based on which the retailer is better able to plan the operation so that the decisions made in the present operation stage do not eliminate future profit-making opportunities or expose the retailer to any major risks. The modular approach, again, aims at an optimal solution of the decision-making problem at hand. By combining these approaches, at least a sub-optimal solution to the global optimization problem can be found. Obviously, this is much better than "to do nothing," or to aim at a global optimal solution by making very risky decisions based on uncertain price and demand forecasts, thereby compromising the viability of the retail business.

The proposed analysis and calculation model for the estimation of the economic impacts of DER control was developed primarily as an analysis tool that gives information of the economic potential of DER in different marketplaces. It was found applicable to the evaluation of the most potential DER applications. The results can be used to focus the limited resources on the implementation of the most potential DER applications. As the proposed methodology and analysis model can give valuable information of the key profit-making opportunities, but also the risks associated with different types of DER use, they can provide an efficient tool for an experienced operator in the planning of the optimal market-based DER use. Although the proposed model enables comprehensive modelling of the problem, an experienced operator is still needed to make the final decisions. It is emphasized that automation of the whole profit optimization process may not be advisable, simply because it can involve operational risks of its own and prevent taking advantage of the past experiences. Nevertheless, the proposed model itself could be developed in the future research, for instance by reducing the workload of the operator by automating trivial processes and integrating additional simulation or analysis tools that support the decision-making.

The proposed comprehensive short-term profit optimization model, including the methodology and the applied modelling approach, is designed by taking into account the key aspects of practical relevance. Some of the present forecasting and modelling applications used by market operators could probably be integrated into the model quite easily to produce the required input data. Still, it is emphasized that the effectiveness of the proposed model depends highly on the performance of the forecasting application, and therefore, the future research could focus on how to complement the model by applying different forecasting tools, and especially, the price forecasting applications that are able to forecast price spikes in different marketplaces.

The main barriers at the moment are linked with the practical implementation of the control actions. Although the current AMR infrastructure provides a basic load control infrastructure, its efficient use on a large scale is hindered by a number of issues. For instance, occasional long data transfer delays, a lack of common operation models, and heterogeneity of systems and solutions including smart meters and data systems result in barriers for the large-scale DER control. In addition, some practical issues such as deficient installations (e.g. the end-user’s loads defectively connected to the control relays of the AMR meter) are found to result in obstacles. Despite these obstacles, the present AMR (Automatic Meter Reading) infrastructure is, in principle, applicable to the implementation of the basic on/off type heating load control, at least in the Elspot market. Basically, this only requires appropriate basic installations, updated meter software/tariffs, and basic data transfer between the market parties, which however, can involve some delays. Consequently, large-scale basic load control in the Elspot market could be provided even with relatively low implementation costs.

The use of the AMR infrastructure for the implementation of the DER control in the reserve markets requires real-time execution and verification of control actions, and thereby, additional investments that inevitably result in additional costs. For instance, implementation of control actions in the balancing power market requires data transfer connections that allow reliable execution of control actions in 15 minutes and almost real-time verification of the control actions. Although the current data transfer solutions that are based on mobile communication technologies may be able to meet these requirements, this may not be the case with solutions based on older power line communication technologies. Therefore, in some cases, also the technical implementation of the data transfer may have to be updated to ensure reliable and real-time execution and verification of control actions in the reserve markets. Implementation of control actions in frequency containment reserve uses (e.g. in the FCR-N and FCR-D markets), on the other hand, calls for local frequency measurements. Therefore, at least software updates of the AMR meters, or even implementation of the missing frequency measurements, are needed.

To sum up, the use of the AMR infrastructure for harnessing the existing DR potential, also in the reserve markets uses, requires standardization of data transfer interfaces and technical requirements, related for instance to the data transfer delays and frequency control functionalities. In addition, common practices for installation of meters and connection of control relays, as well as development of general operation models are needed. From the perspective of general cost effectiveness, these developments should be put into practice at the latest when the next generation AMR meters are installed. Alternatively, DER control actions can be implemented using other technical solutions than AMR such as Home Energy Management Systems (HEMS). In this case, participation of the distribution system operator, who is mainly responsible for the AMR system of the customer, in the implementation of the DER control is not needed. Still, the lack of standardized interfaces and operation models also poses challenges for the large-scale implementation of HEMS-based control solutions. Despite the current obstacles, the emerging smart grid environment can enable a more cost-effective implementation of the proposed profit-optimization model in the long run. In addition, the system is easily scalable, which means that after the establishment of the basic control system, integration of new controllable DER into the system may be more cost efficient.

Based on the research work introduced in this dissertation, future research could focus on how to optimally exploit the proposed short-term profit optimization model, for instance by optimizing the risk constraints and bidding strategies applied. In addition, alternative operation and business models, which can enable cost-efficient harvesting of the DR potential, should be analysed in more detail from the perspective of practical implementation. The increasing penetration of intermittent renewables and energy storages, again, provides signals to analyse the related economic potential and risks. These analyses could also reveal new promising DER control applications, an appropriate combination of which could promote the retailer’s profit optimization. Furthermore, by considering costs associated with the practical implementation of the model, the practical business potential, which includes all the main cost and income components provided by the proposed profit optimization model, could be analysed in more detail.

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Appendix A: Source data of the load profile in Figure 5.4

Data of the retailer's consumption and hedging in the initial stage of the short-term profit optimization (stage 1), based on which the load profile in Figure 5.4 is compiled.

Hour	Total consumption [MWh]	Base consumption [MWh]	CG1 consumption [MWh]	CG2 consumption [MWh]	Physical hedging contracts [MWh]	Total Hedging (Financial + physical) [MWh]
1	106.2	71.7	24.3	10.2	40.0	120.0
2	100.3	65.4	24.3	10.6	40.0	120.0
3	96.5	61.3	24.3	10.9	40.0	120.0
4	96.1	85.3	0.0	10.8	40.0	120.0
5	97.2	86.2	0.0	10.9	40.0	120.0
6	106.0	94.1	0.0	11.9	40.0	120.0
7	126.1	112.6	0.0	13.5	40.0	120.0
8	137.8	122.9	0.0	14.9	40.0	120.0
9	141.8	125.8	0.0	16.0	40.0	120.0
10	140.8	125.0	0.0	15.7	40.0	120.0
11	140.6	124.8	0.0	15.9	40.0	120.0
12	139.5	123.7	0.0	15.8	40.0	120.0
13	138.1	123.1	0.0	15.0	40.0	120.0
14	136.9	122.7	0.0	14.2	40.0	120.0
15	138.2	124.4	0.0	13.8	40.0	120.0
16	142.9	129.6	0.0	13.3	40.0	120.0
17	146.8	134.1	0.0	12.7	40.0	120.0
18	148.5	136.0	0.0	12.5	40.0	120.0
19	148.7	136.2	0.0	12.5	40.0	120.0
20	146.0	133.9	0.0	12.1	40.0	120.0
21	139.8	128.2	0.0	11.6	40.0	120.0
22	125.2	114.6	0.0	10.6	40.0	120.0
23	139.4	104.9	24.3	10.3	40.0	120.0
24	123.4	91.1	24.3	8.0	40.0	120.0

Appendix B: Source data of the load profile in Figure 5.5

Data of the retailer's hedging and estimated consumption after the DER control actions are initially planned based on Elspot prices. The load profile in Figure 5.5 is compiled based on these data.

Hour	Total consumption [MWh]	Base consumption [MWh]	CG1 consumption [MWh]	CG2 consumption [MWh]	Physical hedging contracts [MWh]	Total Hedging (Financial + physical) [MWh]
1	106.2	71.7	24.3	10.2	40.0	120.0
2	100.3	65.4	24.3	10.6	40.0	120.0
3	96.5	61.3	24.3	10.9	40.0	120.0
4	120.4	85.3	24.3	10.8	40.0	120.0
5	121.4	86.2	24.3	10.9	40.0	120.0
6	106.0	94.1	0.0	11.9	40.0	120.0
7	126.1	112.6	0.0	13.5	40.0	120.0
8	137.8	122.9	0.0	14.9	40.0	120.0
9	141.8	125.8	0.0	16.0	40.0	120.0
10	140.8	125.0	0.0	15.7	40.0	120.0
11	140.6	124.8	0.0	15.9	40.0	120.0
12	139.5	123.7	0.0	15.8	40.0	120.0
13	138.1	123.1	0.0	15.0	40.0	120.0
14	136.9	122.7	0.0	14.2	40.0	120.0
15	138.2	124.4	0.0	13.8	40.0	120.0
16	142.9	129.6	0.0	13.3	40.0	120.0
17	146.8	134.1	0.0	12.7	40.0	120.0
18	136.0	136.0	0.0	0.0	40.0	120.0
19	161.2	136.2	0.0	25.0	40.0	120.0
20	146.0	133.9	0.0	12.1	40.0	120.0
21	139.8	128.2	0.0	11.6	40.0	120.0
22	125.2	114.6	0.0	10.6	40.0	120.0
23	115.2	104.9	0.0	10.3	40.0	120.0
24	99.2	91.1	0.0	8.0	40.0	120.0

Appendix C: Source data of the load profile in Figure 5.6

Data of the retailer's hedging, estimated consumption, and current electricity procurements after the initial planning of the balancing operation, based on which the load profile in Figure 5.6 is compiled.

Hour	Total cons. [MWh]	Base cons. [MWh]	CG1 cons. [MWh]	CG2 cons. [MWh]	Physical hedging contracts [MWh]	Total Hedging (Financial + physical) [MWh]	Current physical procurements (Physical deliveries + Elspot trades) [MWh]
1	106.2	71.7	24.3	10.2	40.0	120.0	105.0
2	100.3	65.4	24.3	10.6	40.0	120.0	100.0
3	96.5	61.3	24.3	10.9	40.0	120.0	105.0
4	120.4	85.3	24.3	10.8	40.0	120.0	122.0
5	121.4	86.2	24.3	10.9	40.0	120.0	123.0
6	106.0	94.1	0.0	11.9	40.0	120.0	106.0
7	126.1	112.6	0.0	13.5	40.0	120.0	126.0
8	137.8	122.9	0.0	14.9	40.0	120.0	135.0
9	141.8	125.8	0.0	16.0	40.0	120.0	130.0
10	140.8	125.0	0.0	15.7	40.0	120.0	140.0
11	140.6	124.8	0.0	15.9	40.0	120.0	140.0
12	139.5	123.7	0.0	15.8	40.0	120.0	140.0
13	138.1	123.1	0.0	15.0	40.0	120.0	137.0
14	136.9	122.7	0.0	14.2	40.0	120.0	137.0
15	138.2	124.4	0.0	13.8	40.0	120.0	137.0
16	142.9	129.6	0.0	13.3	40.0	120.0	143.0
17	146.8	134.1	0.0	12.7	40.0	120.0	146.0
18	136.0	136.0	0.0	0.0	40.0	120.0	137.0
19	161.2	136.2	0.0	25.0	40.0	120.0	160.0
20	146.0	133.9	0.0	12.1	40.0	120.0	146.0
21	139.8	128.2	0.0	11.6	40.0	120.0	140.0
22	125.2	114.6	0.0	10.6	40.0	120.0	125.0
23	115.2	104.9	0.0	10.3	40.0	120.0	115.0
24	99.2	91.1	0.0	8.0	40.0	120.0	100.0

Appendix D: Source data of the load profile in Figure 5.7

Data of the retailer's hedging, estimated consumption, and current electricity procurements before planning of the reserve market trades. The load profile in Figure 5.7 is compiled based on these data.

Hour	Total cons [MWh]	Base cons. [MWh]	CG1 cons. [MWh]	CG2 cons. [MWh]	Physical hedging contracts [MWh]	Total Hedging (Financial + physical) [MWh]	Current physical procurements (Physical deliveries + Elspot trades) [MWh]
1	106.2	71.7	24.3	10.2	40.0	120.0	105.0
2	100.3	65.4	24.3	10.6	40.0	120.0	100.0
3	96.5	61.3	24.3	10.9	40.0	120.0	105.0
4	120.4	85.3	24.3	10.8	40.0	120.0	122.0
5	121.4	86.2	24.3	10.9	40.0	120.0	123.0
6	106.0	94.1	0.0	11.9	40.0	120.0	106.0
7	126.1	112.6	0.0	13.5	40.0	120.0	126.0
8	137.8	122.9	0.0	14.9	40.0	120.0	135.0
9	136.3	125.8	0.0	10.5	40.0	120.0	130.0
10	146.3	125.0	0.0	21.2	40.0	120.0	140.0
11	140.6	124.8	0.0	15.9	40.0	120.0	140.0
12	139.5	123.7	0.0	15.8	40.0	120.0	140.0
13	138.1	123.1	0.0	15.0	40.0	120.0	137.0
14	136.9	122.7	0.0	14.2	40.0	120.0	137.0
15	138.2	124.4	0.0	13.8	40.0	120.0	137.0
16	142.9	129.6	0.0	13.3	40.0	120.0	143.0
17	146.8	134.1	0.0	12.7	40.0	120.0	146.0
18	136.0	136.0	0.0	0.0	40.0	120.0	137.0
19	161.2	136.2	0.0	25.0	40.0	120.0	160.0
20	146.0	133.9	0.0	12.1	40.0	120.0	146.0
21	139.8	128.2	0.0	11.6	40.0	120.0	140.0
22	125.2	114.6	0.0	10.6	40.0	120.0	125.0
23	115.2	104.9	0.0	10.3	40.0	120.0	115.0
24	99.2	91.1	0.0	8.0	40.0	120.0	100.0

Appendix E: Source data of the load profile in Figure 5.8

Data of the retailer's hedging, estimated consumption, and current electricity procurements after reserve market trades and before final balancing operation. The load profile in Figure 5.8 is compiled based on these data.

Hour	Total cons [MWh]	Base cons. [MWh]	CG1 cons. [MWh]	CG2 cons. [MWh]	Physical hedging contracts [MWh]	Total Hedging (Financial + physical) [MWh]	Current physical procurements (Physical deliveries + Elspot trades) [MWh]
1	106.2	71.7	24.3	10.2	40.0	120.0	105.0
2	100.3	65.4	24.3	10.6	40.0	120.0	100.0
3	96.5	61.3	24.3	10.9	40.0	120.0	105.0
4	115.4	85.3	19.3	10.8	40.0	120.0	122.0
5	121.4	86.2	24.3	10.9	40.0	120.0	123.0
6	106.0	94.1	0.0	11.9	40.0	120.0	106.0
7	126.1	112.6	0.0	13.5	40.0	120.0	126.0
8	137.8	122.9	0.0	14.9	40.0	120.0	135.0
9	136.3	125.8	0.0	10.5	40.0	120.0	130.0
10	146.3	125.0	0.0	21.2	40.0	120.0	140.0
11	140.6	124.8	0.0	15.9	40.0	120.0	140.0
12	139.5	123.7	0.0	15.8	40.0	120.0	140.0
13	138.1	123.1	0.0	15.0	40.0	120.0	137.0
14	136.9	122.7	0.0	14.2	40.0	120.0	137.0
15	138.2	124.4	0.0	13.8	40.0	120.0	137.0
16	142.9	129.6	0.0	13.3	40.0	120.0	143.0
17	146.8	134.1	0.0	12.7	40.0	120.0	146.0
18	136.0	136.0	0.0	0.0	40.0	120.0	137.0
19	161.2	136.2	0.0	25.0	40.0	120.0	160.0
20	146.0	133.9	0.0	12.1	40.0	120.0	146.0
21	139.8	128.2	0.0	11.6	40.0	120.0	140.0
22	125.2	114.6	0.0	10.6	40.0	120.0	125.0
23	120.2	104.9	5.0	10.3	40.0	120.0	115.0
24	99.2	91.1	0.0	8.0	40.0	120.0	100.0

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