Technical report
Task 5.1 / D5.1.15

27.3.2013

Advanced Bidding Strategies for Trading Wind Power

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Lappeenranta University of Technology
2013

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Acknowledgement

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

Abstract

Wind power has been traditionally traded by using forecast model's point-forecasts as an input. Thus, the bidding strategy has been based on minimizing the balancing energy, which is the main objective of a wind power forecasting tool. However, the costs of balancing are depending on both volume of balancing energy and balancing prices. Therefore, bidding in the day-ahead market by minimizing the balancing energy will not necessarily lead to minimized balancing costs. By taking into account how the balancing prices for up and down regulation are founded in Nordic Regulative Power Market, it is possible to create other bidding strategies, which would minimize the balancing costs. It is shown in this report that the advanced bidding strategies will increase the participant's revenue. The advanced bidding strategies are based on using probabilistic forecasts of market prices, wind energy, balancing power prices and regulation direction. Also, the latest reasearach in the advanced bidding strategies is presented.

Contents

1 Introduction

As the wind energy penetration increases all over the world wind energy is starting to be a major participant in the power system. The annual growth rate of installed wind power has been 25 % in the 21st century and it is likely that the growth will continue in the future as well (EWEA, 2009). The reasons why wind power is preferred source of generation are various. First of all, the share of renewable sources in the power grid must be increased in order to meet the requirements for reducing greenhouse gases. Hydro power capacity is almost used to the fullest in Nordic countries, except in Norway (Norway, 2008). The solar technology has also not been mature technology in the past and it has been too expensive to build. The potential for wind energy has been proven to be large in Nordic countries and together with financial support schemes it is possible to build wind power with a fast pace and thus meet the international requirements set to Finland and increase our energy self-sufficiency. As part of the Finland's target of increasing renewable sources in power grid, Finland should have 2500 MWs (6 % of electricity consumption) of wind power before 2020.

The reason why this report was carried out was to give insight on what kind of environment a wind power participant operates in the electricity market. Trading wind energy, which is a variable and non-dispatchable source of generation, differs from trading of conventional generation which is a non-stochastic source. Especially wind power participant's behaviour in day-ahead and intra-day markets is discussed in more detailed and the literature of the latest research in advanced trading of wind power will be presented. It will be shown how the derivation process of revenue function of a stochastic non-dispatchable source can be carried out. This report has been carried out considering a wind power participant's aspect of short-term power trading, but many of these derivations made in this report can be used for analysing other stochastic energy sources such as solar energy.

Wind energy is still a form of energy, which needs to be supported by the regulator in order to get private investors to invest on wind energy as fast as the target for renewable energy requires. In Finland a Feed-in-Tariff is used, which guarantees a fixed price for a produced unit of energy. However, wind power participants must handle their imbalances through balance settlement, which lowers the maximum possible income. Therefore, wind power participant could increase its revenue by lowering balancing costs. This could be achieved by adding some intelligence on the bidding process, which is discussed in this report. The report is structured in the following manner: In chapter 2 the main characteristics of Nordic power market and especially Spot-market will be presented together with deriving the revenue function of a market participant. In chapter 3, the principle idea of advanced short-term bidding of wind power will be presented and how the risk involved in the short-term trading can be taken into account.

2 Power market

The Nordic electricity market refers to the market area that is shared between Finland, Sweden, Norway, Denmark and Estonia. The main idea behind deregulated power markets, and the common market area, is that having larger inter-connected power system cost-effectiveness and security of supply can be improved. Before the electricity market reform, in the 90's, the electricity market was controlled by the publicly owned utilities and the end users' electricity price was determined by the local electricity distributer. The reasons behind reconstruction, or energy market reform, were to create incentives for cost reductions, which naturally happen when the price is settled in the market, avoid excessive investments to the power grid, improve the selection of investment projects and keep the electricity price as low as possible.

2.1 Electricity Exchange

Nordic short-term electricity exchange, *Nord Pool Spot* is the place for trading physical electricity delivery. The physical marketplace is called as Spot-market and it is where the day-ahead and intra-day electricity exchange is taking place. The financial market is operated by NASDAQ OMX Commodities. Trading in the financial market will not lead to actual, physical, electricity delivery and thus it is mainly used for managing risks. From a wind power participant point of view, the physical market is more important than the financial market and thus it is not necessary to present commodities sold at the financial market in this report. In principle, wind power participant could use financial products to hedge electricity price, but it needs its own expertise and still the participant must sell its production in Spot-markets. The Spot-market is divided into day-ahead and intra-day markets, Elspot and Elbas, respectively. In the following chapters the most important features from an electricity trader's aspect are discussed. More information about the electricity market and exchange can be found in (Partanen, et al., 2009), (Wangensteen, 2006), (NordPool, 2012) and (NASDAQ, 2012).

2.1.1 Elspot

The electricity price is founded in the Elspot-market for every hour by the crossing point of demand and supply curves. The crossing point of the supply and demand curve is called as system price and the energy delivery in Elspot-market is dealt with that price, if the physical limitations are neglected. However, the physical transmission constraints between the price areas must be taken into account, which are limiting the market from functioning properly. When the price areas are in use two incidents will incur: in the overproduction area the area price will lower in comparison to the system price and in the underproduction area the area price will rise. Elspot is not a traditional continuous market where participants are looking for counterparty for the trade. Elspot is a closed auction where bids are placed to the market once a day.

Consumption in the Nordic market area can be considered quasi-constant in a delivery hour whereas the price elasticity of production is greater than for consumption. Therefore, the system price is mainly determined by the consumption; when the consumption is high, the system price tends to rise and while the consumption is low, like on summer months, the system price is lower. Production bids, which are below or equal the system price in a delivery hour, are accepted to the power production and bids, which are above the system price, are not.

It possible to trade tomorrow's physical power delivery in the Elspot -market. The tradable hours are called as *delivery hours* and in Finland the **delivery hours are 01-24** whereas in most of the Nordic countries the delivery hours are one hour behind due to time difference. **The Elspot-market closes at 1 pm.** Finnish time and before that the bids to the market must be submitted (NordPool, 2012). Market participant who owns generation or have customers, submit purchase and/or sale offers for each delivery hour separately. Thus, a wind power producer who needs to sell its generation to the electricity market needs to know how much energy the wind power producer's turbines are producing on each delivery hour. Since the nature of wind is variable and differs greatly from the conventional generation, wind power producer must have some sort of understanding of tomorrow's energy production. This requires the use of *forecast model*, which has at minimum forecast horizon of 12 – 36 h, since the gap from the market closure to first delivery hour is 12 hours.

The Nord Pool was created in the 90's, when the amount of variable generation was marginal from the total electricity production. Thus, the electricity market was created from the perspective of conventional generation, which controllability is on another level than wind power. Therefore, matter like forecasting of generation was not an issue when the deregulated power market was established. In that time more important subject was to forecast demand, which uncertainty was/is an important matter. Still comparing the level of uncertainties between demand and wind power forecasting, the uncertainty of wind power is on another level.

2.1.2 Elbas

Elbas-market is the aftermarket place for Elspot-market where it is possible to adjust bids made in Elspot when the demand or production in a delivery hour is more certain. Mechanism how the Elbas-market works differs from the Elspot-market. Elbas is a continuous real time marketplace, as the traditional stock market is usually presumed to be. In Elbas the electricity buyers and sellers place bids for each delivery hour and when the buyers and sellers bids encounter, the trade is made. Elbas market begins after the prices of Elspot are announced at about 2 pm. and trading is possible **until one hour before the actual delivery hour**. From a wind power producer's point of view Elbas provides a tool for adjusting the sale and purchasing offers as the power production of a delivery hour is more certain.

When more of the energy is contracted in Elbas when the actual power production or demand is more certain, it will cause that less energy settled through *balance settlement.* Since the power system must be in balance on every moment, by having a liquid intra-day marketplace need for regulative energy would be decreased and the power system would be easier to control. In deregulated market electricity exchange is the main responsible for cost effective *unit commitment.* Thus, it is important that the market works properly and contributes *transmission system operators*, TSOs maintaining the system in balance with minimum costs.

2.2 Regulative power market and balancing mechanism

The final market dependent mechanism, which aims to equilibrium between demand and consumption, is carried out in the Nordic regulative market. The main purpose is to correct the net imbalance between bid energy in the Spot-market and actual demand of a delivery hour. The main actors in regulating power market are TSOs, which purposes are to secure continuous power system operation in their own responsible area by maintaining secure power system transmission in whole market area. TSOs of Sweden and Norway are in main responsible for controlling frequency of the Nordic power system.

In the Nordic regulating power market participants can offer their capacity for each delivery hour separately. Regulative bids can be made for increasing or curtailing the power output for one specific delivery hour. Requirements are that the announced capacity must be commenced in 15 minutes and the capacity must be at minimum 10 MWs. The regulating bid must be also placed at latest 45 min before the regulative hour. When all the capacity offers for delivery hour are given, Nordic balancing curve for delivery hour can be formulated. Regulation offers are sorted by their direction (up or down regulation) and price. The balance responsible in the Nordic power system can now commence regulating power as much as it is necessity. The price for regulating energy is the last activated power plant in price order and all of the regulation participants, whose bids are accepted, will receive the same price. Thus, it is not only a practical way to control power grid, it is also a cost effective way to increase or decrease power production in a short time frame.

Wind power participant’s is really difficult to participate into regulating power market since the market requires fully control of the output, and unfortunately wind does not have that property. In some cases, like really windy weather, it could be possible curtail wind power in order to use it as reserve capacity, but there would not be any gain for the wind power producer or society since it is not desirable that cheap marginal cost generation is curtailed by losing cheap energy from the power system.

Balancing the power grid by market-based, TSOs, who are responsible for secure system operation, do not need so much of their own regulation capacity. Therefore, over investments are evaded and costs for society is lowered. However, TSOs are responsible to take action in case of disturbance in power system. Rule of thumb has been that in power system must have disturbance reserve as much as the biggest production unit. Thus, the power system must maintain the loss of the biggest production unit. This is called as N-1 dimensioning.

The purpose of the balance power trade is to balance monetarily the differences between contracted deliveries and supply and the actual deliveries and supply, which are determined in the *balance settlement*. In the balance settlement actual production and supply are determined between three different parties: National, balance provider and

Distribution System Operator, DSO. The output of this study is used in the balance settlement, where the balance is traded between balance responsible (Fingrid in Finland) and balance providers. Balance provider can usually comprise many DSOs, or in some cases just one large DSO.

Balance power trade is divided into *production and consumption balance*. In production balance two-price model is used, which means that there are different prices for negative and positive imbalances. In consumption balance only one price is used for imbalances for both regulation directions. Balance power trade is closely connected to the regulative power market since the prices used in balance settlement comes from the regulative power prices. Thus, it is good to notice that for trading electricity, controlling power grid though regulative power market and settling the balances, the time unit is always one hour. This is natural since all of the previously mentioned markets and mechanism are connected to each other.

The difference between area and balancing price depict the costs of regulation. In this paper the difference between area and regulation price is called as *unit balancing cost*. The average Elspot prices in Finland and unit balancing costs are presented in Figure 2.1. The balancing costs are shown as black error bars and the balancing costs are following area prices, as they should. The unit balancing costs have varied greatly from year to year. For instance, for year 2012 the average up regulation cost was 9.6 €/MWh and down regulation cost was -4.9 €/MWh. Therfore, there has been a great asymmetric in unit balancing costs, which causes that balancing costs for up regulation error have been greater than for down regulation errors.

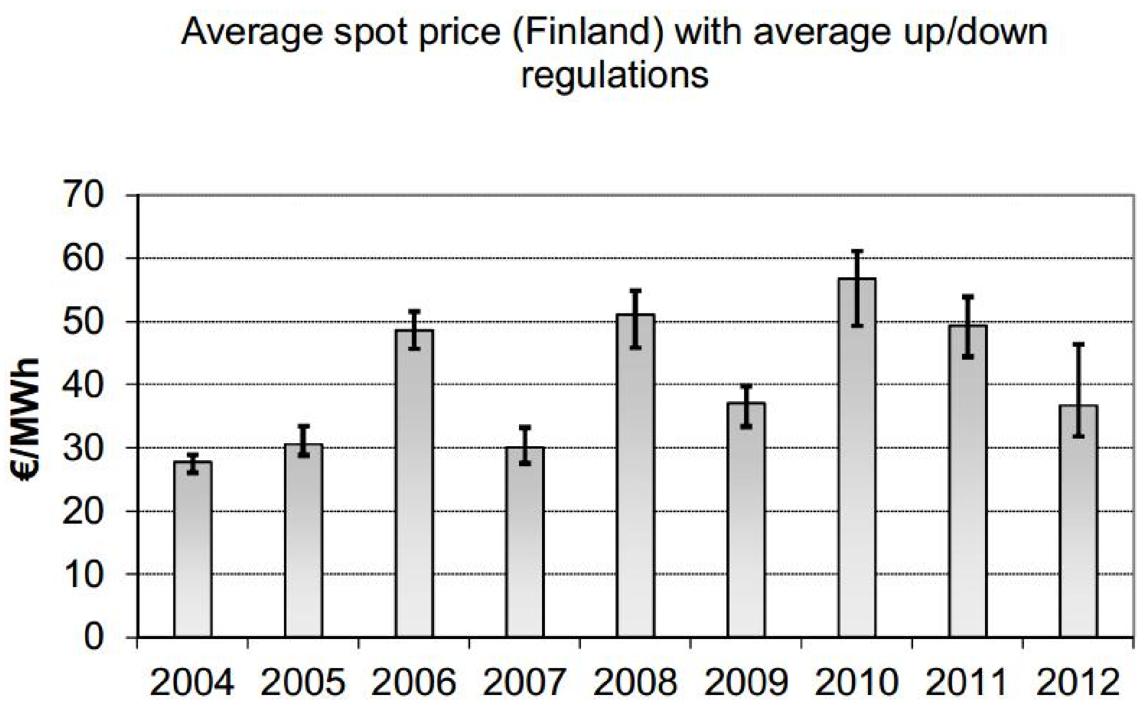

Figure 2.1 Average Finnish area prices (grey bars) and average balancing unit costs for year 2004-12 (Holttinen, et al., 2013).

In (Miettinen, 2012) the periodically of balancing costs is studied. Not only the volume of unit balancing costs is somewhat periodic, but the regulation direction has some periodic characteristics. Since the imbalances are penalized only to the disadvantageous direction from the system point of view. It would be important for a wind power participant to know that what direction the system balance is in order to avoid the disadvantageous regulation direction.

The balancing prices for production are constructed in manner so that imbalances, which are helping system operators maintaining the frequency on its nominal value, will not be penalized. Thus, these producers can handle their imbalances with Elspot-price. Whereas, imbalances to the disadvantageous direction are penalized so that the producer will pay by the price, which is the corresponding regulative power price in that hour. For example wind power participant, who has predicted too much energy production in a delivery hour, must pay the imbalance energy with the sale price of balancing energy. Now, the balancing cost for a producer depends whether the imbalance hour is on the system level down or up regulation hour and the cost of balancing is either zero or a positive number. In principle, the Nordic two-price balancing mechanism is constructed in a manner so that one cannot gain anything from the imbalances.

For consumption balances where one-price model is used, one direction of deviations is always penalised and the other direction is awarded, which makes it clearly more suitable for wind power producer if it would be also used for production balance (Holttinen & Stenberg, 2011). The problem with one-price model, compared to two-price model, is that market participant might not have incentives to predict accurately for its production, since from balancing market it might be possible to get cheaper electricity. From the market participant point of view important aspect of balancing prices is that the prices do not depend on the volume of imbalance energy. Thus, the cost relationship to the imbalance volume is linear.

Wind power participant can affect its balancing costs by bidding in Spot-market. Since, all of the markets are connected to each other; experienced bidder could consider the price mechanisms of the balance power trade when bidding in Spot-market and perhaps could avoid expensive balancing prices. The present balancing trade system is constructed in a manner, which allocates imbalance costs to participants who have imbalances to the disadvantageous direction, than rather thinking power system as a joint market, where the control of the system is on everybody’s responsibility. The pricing mechanism of balancing power is important to the wind power participant, since the nature of wind is variable and non-dispatchable and thus the imbalances are always present. However, one must bear in mind that wind power will cause extra costs to the power system as the share of non-dispatchable generation increases, which has also low inertia (Holttinen, 2004). **The main questions are that how much additional regulating capacity is needed as the wind power penetration increases, how the variable nature of wind power affects to the power system and what is the future unit cost of balancing energy.** These all are important question for a wind power participant, since the tradition has been that many of the costs that wind power induces to the power system, producer might have to pay for compensating the effects.

3 Trading of wind energy in short-term electricity markets

In this chapter the revenue function of stochastic generation in Spot-markets is presented. Also, the Advanced bidding method *Expected Utility Maximization*, EUM will be presented and the risk of trading with advanced bidding methods will be discussed.

3.1 Wind power participant's revenue function

The bids are placed into the market with a fixed time interval, which is the Program Time Unit, PTU. The PTU in physical, regulative and balancing market is one hour. Let's first assume that the bids can be only placed in the Elspot market and the imbalances are dealt in the balancing mechanism. Let $\widetilde{W}_k^{(S)}$ denote the amount of energy contracted in the Elspot market for the hour k, and let W_k be the stochastic production of wind energy in that same PTU. The imbalance term must also be then stochastic, which can be written as $W_k - \widetilde{W}_k^{(S)}$. Now that the energy balances of a bidding process are presented, a function for revenue can be formulated by using appropriate prices for Elpot and balance energy. The revenue ρ_k can be expressed as the sum of revenue in Elspot market, $\rho_k^{(S)}$ and balancing mechanism $\rho_k^{\uparrow/\downarrow}$.

$$\rho_k = \rho_k^{(S)} + \rho_k^{\uparrow/\downarrow} \tag{3.1}$$

The revenue in Elspot market can be determined by the contracted energy and the respective Elspot area price, $\pi_k^{(S)}$

$$\rho_k^{(S)} = \pi_k^{(S)} \widetilde{W}_k^{(S)} \tag{3.2}$$

Traditionally the wind power participant's bid energy $\widetilde{W}_k^{(S)}$ in the day-ahead Elpot-market has been the *point forecast* of a forecast model, which is the most likely outcome of energy production in a delivery hour. The revenue in the balancing mechanism is depending whether the participant has surplus of energy $W_k \geq \widetilde{W}_k^{(S)}$ or deficit of energy $W_k \leq \widetilde{W}_k^{(S)}$. The imbalance prices for down, $\pi_k^{\downarrow}$ and up $\pi_k^{\uparrow}$ regulation are both positive. Thus, for negative imbalance (deficit) the revenue is negative and for positive imbalance (surplus) the revenue is positive.

$$\rho_k^{(\uparrow/\downarrow)} = \begin{matrix} \pi_k^{(\downarrow)}\left(W_k - \widetilde{W}_k^{(S)}\right), & W_k \geq \widetilde{W}_k^{(S)} \\ \pi_k^{(\uparrow)}\left(W_k - \widetilde{W}_k^{(S)}\right), & W_k \leq \widetilde{W}_k^{(S)} \end{matrix} \tag{3.3}$$

There are couple of properties to imbalance prices, which are result from how the Nord Pool functions. First of all the imbalance prices are bounded such that

$$\begin{aligned} \pi_k^{(\downarrow)} &\leq \pi_k^{(S)} \\ \pi_k^{(\uparrow)} &\geq \pi_k^{(S)} \end{aligned} \quad (3.4)$$

The system net imbalance can be stated as the deviation between planned total production, $\widetilde{TP}_k$ and the actual total production, TP_k and assumed consumption, $\widetilde{TC}_k$ in the system, and actual consumption, TC_k in a delivery hour.

$$\left(\widetilde{TP}_k - TP_k\right) - \left(\widetilde{TC}_k - TC_k\right) \quad (3.5)$$

The system imbalance is measured from the whole interconnected Nord Pool market area, since the whole system is controlled through the regulative market, which determines the balancing prices for up and down regulation. During the hour of positive system surplus (production exceeds consumption), down regulative power is needed in order to maintain the system in balance. Thus, the hour is down regulation hour, and in the Nord Pool following relations hold

$$\begin{aligned} \pi_k^{(\downarrow)} &= \pi_k^{(S)} \\ \pi_k^{(\uparrow)} &\geq \pi_k^{(S)} \end{aligned} \quad (3.6)$$

When the system balance is negative in a delivery hour, the hour is called as up regulation hour. Then the next relations will hold

$$\begin{aligned} \pi_k^{(\downarrow)} &\leq \pi_k^{(S)} \\ \pi_k^{(\uparrow)} &= \pi_k^{(S)} \end{aligned} \quad (3.7)$$

The relations presented in equations (3.6) and (3.7) are based on the idea that all the imbalances, which profit maintaining the system in balance, are not penalized. However, the regulation to the disadvantage direction is penalized, and the penalize price is depending on the total volume of regulation in that hour. When the system is in perfect balance, and thus there is no need for regulative power, next equation is valid.

$$\pi_k^{(S)} = \pi_k^{(\uparrow)} = \pi_k^{(\downarrow)} \quad (3.8)$$

It is possible to formulate equation (3.1) differently by using the previously mentioned properties of balancing prices. Then the revenue function can be formulated so that the first term illustrates the maximum possible income and the latter term is the cost of imbalance. In the equation (3.9) modified revenue function.

$$\rho_k = \pi_k^{(S)} W_k + C_k^{(\uparrow/\downarrow)}, \quad (3.9)$$

where $C_k^{(\uparrow/\downarrow)}$ is the cost of imbalance. Since, the first term $\pi_k^{(S)}\, W_k$ in equation (3.9) is not depending any way on the decision made at Elspot-market, the maximum revenue can be achieved if the latter term in equation (3.9) is zero. Fortunately wind power participant can effect on the latter term on some extent. At this point it can be also possible to see why curtailment of power is uneconomic. Curtailment leads to situation that the first term in equation (3.9) decreases. Usually the next relation is valid:

$$\pi_k^{(S)} \gg \left|\psi_k^{(\uparrow/\downarrow)}\right|, \tag{3.10}$$

where the $\psi_k^{(\uparrow/\downarrow)}$ is the unit cost of balancing for positive and negative imbalances. This mean that for a wind power participant the traded energy from Elspot-trading is more valuable than the possible gain by curtailing energy production and having less costs at the balance settlement. Second term in equation (3.9) can be written as

$$C_k^{(\uparrow/\downarrow)} = \begin{matrix} \psi_k^{(\downarrow)}\left(W_k - \widetilde{W}_k^{(S)}\right), & W_k \geq \widetilde{W}_k^{(S)} \\ \psi_k^{(\uparrow)}\left(W_k - \widetilde{W}_k^{(S)}\right), & W_k \leq \widetilde{W}_k^{(S)} \end{matrix} \tag{3.11}$$

where the unit regulation costs $\psi_k^{(\downarrow)}$ and $\psi_k^{(\uparrow)}$ for positive and negative deviations from contracted energy are

$$\begin{aligned} \psi_k^{(\downarrow)} &= \pi_k^{(\downarrow)} - \pi_k^{(S)} \\ \psi_k^{(\uparrow)} &= \pi_k^{(\uparrow)} - \pi_k^{(S)} \end{aligned} \tag{3.12}$$

By taking into account the constraints in the equation (3.4) one can see that the imbalance costs term $C_k^{(\uparrow/\downarrow)} \in [-\infty, 0]$. However, the lower limit of the unit balance cost term cannot reach $-\infty$, since the maximum possible Elspot-price in the Nord Pool can only be 2000 €/MWh and the maximum up regulation offer cannot exceed 5000€/MWh (Fingrid, 2009). Thus, the maximum unit loss is bounded to 5000 €/MWh.

Similar formulations can be made when intra-day market, Elbas is included. As a result following equation can be created

$$\rho_k = \pi_k^{(S)}\left(W_k - \widetilde{W}_k^{(E)}\right) + \pi_k^{(E)}\widetilde{W}_k^{(E)} + C_k^{*(\uparrow/\downarrow)} \tag{3.13}$$

Where the regulation cost function, $C_k^{*(\uparrow/\downarrow)}$ is

$$C_k^{*(\uparrow/\downarrow)} = \begin{matrix} \psi_k^{(\downarrow)}\left(W_k - \left(\widetilde{W}_k^{(S)} + \widetilde{W}_k^{(E)}\right)\right), & W_k \geq \left(\widetilde{W}_k^{(S)} + \widetilde{W}_k^{(E)}\right) \\ \psi_k^{(\uparrow)}\left(W_k - \left(\widetilde{W}_k^{(S)} + \widetilde{W}_k^{(E)}\right)\right), & W_k \leq \left(\widetilde{W}_k^{(S)} + \widetilde{W}_k^{(E)}\right) \end{matrix} \tag{3.14}$$

Equation (3.13) interprets that the bid energy at Elbas lowers maximum income Elspot market relative to the bid energy at Elbas, but increases the total revenue by $\pi_k^{(E)}\widetilde{W}_k^{(E)}$. Thus, from optimization point of view, if relation $\pi_k^{(E)} > \pi_k^{(S)}$ holds one should only bid to Elbas-market only, and contrary for $\pi_k^{(E)} < \pi_k^{(S)}$. However, Elbas-market is primarily used for focusing the production forecast before a delivery hour. Thus, the decisions in Elspot and Elbas can be though as independent and therefore bidding strategy in Elspot does not necessarily need to consider existence of Elbas. However, if the intra-day markets would for instance reflect actual power production costs of energy in power system, it might be wise to consider this when placing the bid in Elspot-market. The turnover of Elspot is more than one hundred time larger than the turnover of Elbas. Thus, the Elspot is the main marketplace for having physical electricity exchange (NordPoolSpot, 2009).

3.2 Bidding strategies

Wind power can be considered as an example of a stochastic and non-dispatchable source of generation. Thus, it is necessary to forecast wind power production at day-ahead basis in order to trade it. The forecasting can be only performed with limited accuracy since it involves forecasting of weather, which is known to be a difficult task (Lorenz, 1969). There have been carried out state-of-art forecasting reports by (Monteiro, et al., 2009) and (Giebel, et al., 2011), which both outlines the development in wind power forecasting in the past couple of decades.

Wind power must be traded in electricity market alongside conventional generation. In Nordic electricity market the day-ahead market is the dominant market mechanism. Thus, the forecasts horizon is at minimum 12-36 hours ahead, which causes uncertainty on delivery hours power production and prediction errors. The imbalance energy is the difference between contracted power in day-ahead and intra-day trading and actual energy production in a delivery hour. When the wind power producer owns other generation besides wind power (or owns wind turbines on different sites), it leaves an option to adjust production balance as combined portfolio. This might be profitable if the producer owns dispatchable generation, which can be used to adjust the imbalances that the non-dispatchable generation induces. See for instance (Angrarita, et al., 2009) how the stochastic optimization of hydro power can be carried out and (Acker, 2011) how the negative impacts of wind power in electrical system with hydro power can be reduced by using hydro power. Also, (García-González, 2008) showed how the pumped hydro-storage can be used to create hedging strategies for a wind power participant.

Although, producers try to minimize the imbalance energy it is only natural that contracted energy differs from the actual. Since the prices for imbalance energy are usually disadvantageous compared to day-ahead prices, it has been custom to minimize imbalance energy in order to minimize balancing costs. However, this can be only valid if the unit balancing costs are symmetric, which means that there is a same cost for having a certain volume of imbalance energy for both regulation directions. However, in the Nordic market the prices are usually asymmetric and thus the regulation direction to other direction is more disadvantageous than for other.

Different bidding strategies have been developed in the literature, which main purpose is to minimize regulation losses of a wind power participant. (Jónsson, 2012) has been recited a good list of research articles on bidding strategies, which can be applied to day-ahead bidding. The newly made state-of-art research has been made on assumptions that it is possible to create probability information of wind power production, balancing prices and Elspot-prices and then use linear programming techniques for finding the best possible combination of day-ahead bid and intra-day bid, when the distribution of balancing costs are known. For instance in (Matevosyan & Söder, 2006) a complete procedure for creating bidding strategies that minimizes imbalance costs by using mixed integer programming has been introduced. In (Morales, et al., 2010) it was shown how by using ARIMA-models and linear programming one can find optimal solutions for contract volumes on different markets. The analytical solution of optimal bid in day-ahead market was presented by (Dent, et al., 2011), where the optimal bid can be found without using any linear programming formulations. However, very extensive work has been made in (Jónsson, 2012), where the optimal bids for day-ahead trading were carried out for price-taker and price-marker assumptions and the optimal bid was found by writing the bidding problem as a mixed integer problem. In (Bourry & Kariniotakis, 2009) bidding strategies were extended also to intra-day trading. When creating different bidding strategies, risks involved on maximizing (or minimizing) utility function are paramount. How the risks are usually considered on the bidding process will be presented in the chapter 3.2.3.

In the next chapter a bidding strategy is presented, where it is possible to see where the imbalance cost minimization is based. It is assumed that the wind power participant is a *price taker*, which means that the participant's actions in the markets do not reflect to the system price in any way. Thus, in other words market participant do not have any market power. It was shown that the wind power in Denmark affects Elspot-price significantly (Jónsson, et al., 2009). However, it is important to understand the difference between Denmark and Finland as Nord Pool price areas. In Finland the wind energy penetration is 0.6 % from the electricity consumption, whereas in Denmark the corresponding figure is 28 % (DWIA, 2011) (VTT, 2012). Besides the significant difference on the energy penetration, Finland is on geographic area much larger than Denmark. Thus, the spatial smoothing effect is greater in Finland than in Denmark, which decreases the effects that wind power induces to the power system.

3.2.1 Expected utility maximization, EUM

The presented optimal bidding method in this chapter has been used widely on the literature. In (Zugno, et al., 2012) the method is called as Expected Utility Maximization, EUM and it was introduced by (Bremnes, 2004). Bidding strategies based on EUM and stochastic optimization in electricity market was also studied in (Linnet, 2005). Finally, in (Pinson, et al., 2007) complete bidding process and simulation based on probabilistic forecasts of wind power was introduced. EUM leads to optimization of piecewise linear loss function. However, in (Pinson, et al., 2007) also other loss functions were studied. The final steps on the literature based on EUM were taken by (Zugno, et al., 2012), where the constrained EUM-bid was introduced and all the simulations were made by using state-of-art electricity price and wind generation forecast methods.

Equation (3.9) illustrates how the wind power participant's revenue depends on two different terms. The simulations are usually made only for including day-ahead market, since the intra-day market in Nordic countries is not liquid enough for modelling purposes. The first revenue term in equation (3.9) is assumed to be out of reach since it is economic to produce as much as energy it is possible. Thus, the wind power participant's revenue depends on the second term, which is the cost of imbalance, $C_k^{(\uparrow/\downarrow)}$. The cost of imbalance is function of unit regulation costs and corresponding imbalance. If the unit regulation costs for negative and positive imbalance are equal $\left(\left|\psi_k^{(\downarrow)}\right| = \psi_k^{(\uparrow)}\right)$, it is clear that the wind power participant should minimize the imbalance energy. However, if the unit regulation costs are not equal $\left(\left|\psi_k^{(\downarrow)}\right| \neq \psi_k^{(\uparrow)}\right)$, wind power participant should consider that it is more unprofitable to have imbalances to the other direction. For instance, if the unit regulation costs are $\psi_k^{(\uparrow)} = 1.5 \cdot \left|\psi_k^{(\downarrow)}\right|$, and the imbalance energy is assumed to be W_k^{ib}. Then the balancing cost for positive and negative prediction error are

$$C_k^{(\uparrow/\downarrow)} = \begin{cases} \psi_k^{(\downarrow)} W_k^{ib} = \psi_k^{(\downarrow)} W_k^{ib}, & W_k^{ib} \geq 0 \\ \psi_k^{(\uparrow)} W_k^{ib} = 1.5 \cdot \left|\psi_k^{(\downarrow)}\right| W_k^{ib}, & W_k^{ib} \leq 0 \end{cases} \tag{3.15}$$

It is possible to see from the equation (3.15) that the cost of balancing energy is 1.5 folded for negative imbalances when the volume of imbalance energy is same. In case of conventional generation when the power output can be controlled, it might be reasonable to minimize imbalance energy, W_k^{ib}. However, when trading wind energy, which cannot be controlled, the participant should adjust its bid so that the imbalance energy goes to the 'safety side' where the unit cost of regulation is smaller – if possible.

Generally the maximization of profit must be carried out in the long term. For instance maximization of hydro power plant's revenue is a complicated problem, which is usually carried out on time horizon of months to a year. However, in case of wind power, revenue maximization can be done considering only tomorrows delivery hours. In day-ahead market the maximization of revenue can be formulated as it was shown in (Zugno, et al., 2012)

$$\widetilde{\boldsymbol{W}}^{(S)} = \underset{\widetilde{\boldsymbol{W}}^{(S)}}{\arg\max}\, \mathbb{E}\left\{\sum_{\mathrm{k}=i_{\mathrm{PTU}}}^{f_{\mathrm{PTU}}} \rho_{\mathrm{k}}\right\}, \tag{3.16}$$

where i_{PTU} and f_{PTU} are the shortest and longest lead-times from the closure of day-ahead trade. Since, the marginal cost of wind energy is not depending of produced power; the wind power participant always tries to maximize the produced energy. Thus, it is possible to assume time-independent decisions over time and the maximization function of revenue in equation (3.16) is equal to the sum of maximization of the revenue obtained at each k. Thus the optimal bid, $\widetilde{W}^{(S)}$ is

$$\widetilde{W}^{(S)} = \arg\max_{\widetilde{W}_k} \mathbb{E}\{\rho_k\} \tag{3.17}$$

where the revenue ρ_k can be formulated as in equation (3.9). The first term in the equation (3.9) illustrates the maximum income of a wind power participant and thus it can be leaved outside of the maximization problem. Therefore, the optimal bid can be founded by maximizing the expectation of balancing cost, since the balancing costs are non-positive.

$$\widetilde{W}^{(S)} = \arg\max_{\widetilde{W}_k} \mathbb{E}\left\{C_k^{(\uparrow/\downarrow)}\right\} \tag{3.18}$$

The nature of balancing costs is stochastic, asymmetric and piecewise linear and therefore the problem is a variant of the well know linear terminal loss problem, as it is discussed in (Zugno, et al., 2012). Assuming that the probability information of unit regulation costs is available and that the unit up and down regulation cost are independent from the producer's imbalance volume, these stochastic costs can be replaced with *certainty equivalents* in the optimization process, as it was shown in (Zugno, et al., 2012). In this report it is assumed that the whole distributions of unit regulation costs for positive and negative deviations are known. The independency assumption is quite reasonable, but as (Zugno, et al., 2012) mentions there can be cases when in high wind penetration countries some large weather phenomena (i.e. large weather fronts) could affect both the wind power production and regulation costs at the same time by losing the independency assumption. The optimization problem can be made explicit if it is assumed that probability information for future wind energy and unit regulative costs are available

$$\begin{aligned}\mathbb{E}\left\{C_k^{(\uparrow/\downarrow)}\right\} = &\int_0^{\infty}\int_0^{\widetilde{W}^{(S)}} \psi_k^{(\uparrow)}(W_k - \widetilde{W}_k^{(S)}) f_{\psi_k^{(\uparrow)}}(\psi_k^{(\uparrow)}) d\psi_k^{(\uparrow)} f_{W_k}(W_k) d\,W_k \\ &+ \int_{-\infty}^{0}\int_{\widetilde{W}^{(S)}}^{W^{max}} \psi_k^{(\downarrow)}(W_k - \widetilde{W}_k^{(S)}) f_{\psi_k^{(\downarrow)}}(\psi_k^{(\downarrow)}) d\psi_k^{(\downarrow)} f_{W_k}(W_k) d\,W_k\end{aligned} \tag{3.19}$$

where $f_X(\cdot)$ is the probability density function of variable X and W^{max} is the WPP's maximum energy production in one PTU. When assuming that the unit regulation cost and wind power production are independent variables, it is possible to separate the double integral, equation (3.20). Also for convenience following substitutions are used: $d\mathbb{P}_{\psi_k^{(\uparrow)}} = f\left(\psi_k^{(\uparrow)}\right) d\psi_k^{(\uparrow)}$, $d\mathbb{P}_{\psi_k^{(\downarrow)}} = f(\psi_k^{(\downarrow)}) d\psi_k^{(\downarrow)}$ and $\mathbb{P}_{W_k} = f(W_k) d\,W_k$.

$$\mathbb{E}\left\{C_k^{(\uparrow/\downarrow)}\right\} = \int_0^{\infty} \psi_k^{(\uparrow)} d\mathbb{P}_{\psi_k^{(\uparrow)}} \int_0^{\widetilde{W}^{(S)}} \left(W_k - \widetilde{W}_k^{(S)} \right) d\mathbb{P}_{W_k} + \int_{-\infty}^{0} \psi_k^{(\downarrow)} d\mathbb{P}_{\psi_k^{(\downarrow)}} \int_{\widetilde{W}_k^{(S)}}^{W^{max}} \left(W_k - \widetilde{W}_k^{(S)} \right) d\mathbb{P}_{W_k} \tag{3.20}$$

By substituting the expected values of unit regulation costs $\hat{\psi}_k^{(\uparrow)}$ and $\hat{\psi}_k^{(\downarrow)}$ it is possible to achieve

$$\mathbb{E}\left\{C_k^{(\uparrow/\downarrow)} | \widetilde{W}_k^{(S)}\right\} = \hat{\psi}_k^{(\uparrow)} \int_0^{\widetilde{W}^{(S)}} (W_k - \widetilde{W}_k^{(S)}) \, d\mathbb{P}_{W_k} + \hat{\psi}_k^{(\downarrow)} \int_{\widetilde{W}_k^{(S)}}^{W^{max}} (W_k - \widetilde{W}_k^{(S)}) d\mathbb{P}_{W_k} \tag{3.21}$$

However, by applying the theory of certainty equivalents is it possible to obtain similar results, but without using the total distribution of unit regulation costs. It is possible to solve the optimization problem presented in equation (3.18), by using the equation (3.21). Only the solution of expected utility maximization bid in Elspot market, $\widetilde{W}^{(S)}$ will be presented, equation (3.22)

$$\widetilde{W}^{(S)} = F_{W_k}^{-1}\left(\frac{\left|\hat{\psi}_k^{(\downarrow)}\right|}{\hat{\psi}_k^{(\uparrow)} + \left|\hat{\psi}_k^{(\downarrow)}\right|} \right) \tag{3.22}$$

where $F_{W_k}^{-1}$ is the inverse CDF function of wind energy production in the hour k. Therefore, the expected utility maximization bid can be found from a certain quantile of a prediction distribution of energy production in the k^{th} hour. The optimal quantile is determined by the probability, r_k which depends on the relation of up and down regulation costs

$$r_k = \frac{\left|\hat{\psi}_k^{(\downarrow)}\right|}{\hat{\psi}_k^{(\uparrow)} + \left|\hat{\psi}_k^{(\downarrow)}\right|} \tag{3.23}$$

One can now see that $r_k \in [0,1]$, since $r_k = 0$ can be achieved when the $\left|\hat{\psi}_k^{(\downarrow)}\right| = 0$, and if the $\hat{\psi}_k^{(\uparrow)} = 0$ then $r_k = 1$. The solution is also valid since the properties of CDF insist that $\lim_{x \to -\infty} F(x) = 0$ and $\lim_{x \to \infty} F(x) = 1$.

In order to use the EUM-method one must have a wind power forecast tool, which can derive W_k for PTUs from i_{PTU} to f_{PTU}, see definition in equation (3.16). This forecast tool primary function is to minimize forecast errors on different delivery hours. The forecast tool must also provide median centred forecasts since it is possible to see from the equation (3.23) that when the up and down unit balancing cost are equal $\Big(\hat{\psi}_k^{(\uparrow)} =$

$\hat{\psi}_k^{(\downarrow)}\big)$ then there should not be any reason to adjust bid $(r_k = 0.5)$. In order to use EUM-strategy one must also have a probabilistic forecast tool for deriving $\hat{\psi}_k^{(\uparrow)}$ and $\hat{\psi}_k^{(\downarrow)}$.

3.2.2 Simulation of EUM

In the previously chapter bid, which maximizes expected utility was presented. However, when looking at the properties of EUM-bid, which is presented in equation (3.22), one can notice some extreme behaviour as the properties of unit balancing costs are considered. Unit balancing cost differs from zero to the other regulation direction while the unit balancing cost to the other direction is zero. Thus, the ratio, r_k tends to vary between the extreme values 0 and 1. Therefore, a wind power participant should either bid in the Elspot market nothing or the maximum capacity, W^{max}. When the sign of actual unit balancing cost differs from the forecasted, or the behaviour is not as extreme as forecasted, it is possible that the wind power participant results with significant financial losses. Thus, it is possible to understand that there is a *risk* when using EUM bidding strategy.

In (Miettinen, 2012) this previously mentioned problem was stated. However, in (Zugno, et al., 2012), measures were taken in order to reduce this effect. Constraints were added to the EUM bid, which would reduce the extreme behaviour of the method. The constraints were added either in decision space or in probability space. In the decision space the constraints were directed to the point forecast, $\widehat{W}_k$ so that the bid value must be on a certain radius from the $\widehat{W}_k$, i.e. 20 % from the $\widehat{W}_k$. In the probability space the constraints were added to the ratio r_k, with a similar logic than in the decision space. However, the probability constraints were centred on the value of cumulative distribution, F_{W_k} at the point forecast $\widehat{W}_k$.

It can be noticed that these constraints improved wind power participant's revenue, as it is illustrated in the Figure 3.1. The blue line in the figure is the cumulative revenue by using the EUM bidding strategy and the other lines represents the different constraints methods with different allowed intervals. It is possible to see that the revenue from using EUM bid is quite volatile, which is proven to be caused by the extreme behaviour of EUM bid. When the constraints are included to the bid, the revenue is clearly improved. By adding the constraints to the bid it is possible to achieve bid that clearly improves the revenue without using time consuming linear optimization methods.

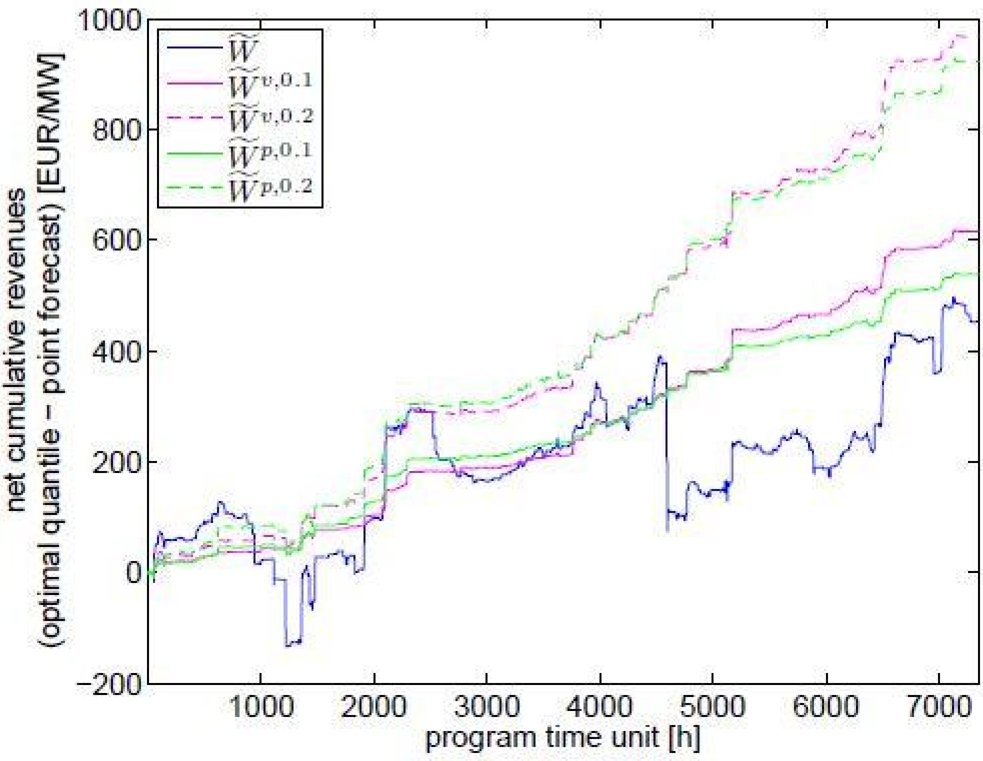

Figure 3.1 Improvement of revenue by adding constraints to the EUM bidding strategy. Superscript indexes *v* and *p* incept value and probability and the number after the indexes describes the radius of the constraint (Zugno, et al., 2012).

3.2.3 Risks of bidding

The example in the previous chapter illustrated that using the EUM-bid might not be the optimal way to increase wind power participant's revenue. The reason why pursuing maximum utility should not be the 'optimal' solution is the *risks* involved on EUM-bidding. Therefore, a higher income is reached by adding constraints to the EUM-method than without using any limitations. However, the constrained EUM-method has some limitations. Putting the limitation only for deviation of point forecast, addresses the uncertainty of production in a delivery hour but do not consider the uncertainty on the unit regulation costs. Thus, it is possible that the wind power producer could still end up with significant losses if the deviation from point forecast is inside the allowed radius but the unit regulation cost differs greatly from the forecasted value. Therefore, a small deviation with big penalty set to it can cause significant drawback on the revenue. EUM-bid does not also consider the Elspot price risk, which will be discussed in this chapter.

It is possible to distinguish different strategies by their level of risks. For now on a bid, which purpose is to make decisions on the expected income is termed as *risk-neutral*. Therefore, the EUM bidding strategy is seen from the risk point of view as risk-neutral. When a wind power participant is not reaching for the maximum possible income but it is instead trying to avoid losses, the strategy is termed as *risk-averse*. For instance, trading using point forecast as bids will be seen as *risk-averse* since it minimizes balancing energy. The constrained EUM bidding strategy is also risk-averse, since it limits extreme behaviour but considers that prices are asymmetric. By increasing the radius, the bidding strategy will move towards risk-neutral as it is more like EUM bidding strategy.

Recently many studies has been carried out on developing risk aversion strategies on day-ahead market (Dent, et al., 2011) (Jónsson, et al., 2012) (Bourry, et al., 2008). The methods used in the risk-aversion in day-ahead trading are coming from the financial industry. The most popular risk-aversion methods in the literature are *Value-at-Risk*, VaR and *Conditional Value-at-Risk*, CVaR, which are usually used to provide quantification of company's portfolio exposure to a risk. The VaR is defined by definition: VaR_{α} at a risk level of α is the lowest amount x such that the probability that the losses, L exceeds x is not larger than $1-\alpha$ (Sarykalin, et al., 2008).

$$VaR_{\alpha} = min\{x: P(L > x) \leq 1 - \alpha\} \tag{3.24}$$

By using the cumulative distribution of losses, F_L

$$\mathrm{VaR}_{\alpha} = min\{x: F_L(x) \geq \alpha\} = min\{x: q_l(\alpha) \geq x\} \tag{3.25}$$

Thus the VaR_{α} is the α-quantile of a distribution, $F_L(x)$. VaR_{α} is very popular measure of risk in the financial industry mostly because it is very simple to illustrate. The problem is that the mathematical characteristics of VaR_{α} are undesired, such as it is not convex and it lacks sub-additivity. Thus, in many scientific papers has been end up using CVaR_{α}, which is a coherent risk measure. Conditional value-at-risk or expected shortfall measures expectation value for values that that exceeds VaR_{α}. Thus, it measures more severe losses than the value-at-risk method. For the continuous distributions:

$$\begin{aligned} CVaR_{\alpha} &= \mathbb{E}\{L: L \geq VaR_{\alpha}\} \\ &= \frac{1}{1-\alpha}\int_{\alpha}^{1} \mathrm{VaR}_{\alpha}(L)d\alpha = \frac{1}{1-\alpha}\int_{\alpha}^{1} q_X(\alpha)d\alpha \end{aligned} \tag{3.26}$$

where $q_X(\cdot)$ is the quantile function. More about the mathematical properties of these methods can be found in (Rockafellar & Uryasev, 2000). In Figure 3.2 loss distribution where the VaR_{α} and CVaR_{α} values of a loss distribution are presented with a certain risk level, α. One can notice how the conditional value-at-risk is more conservative from the risk point of view.

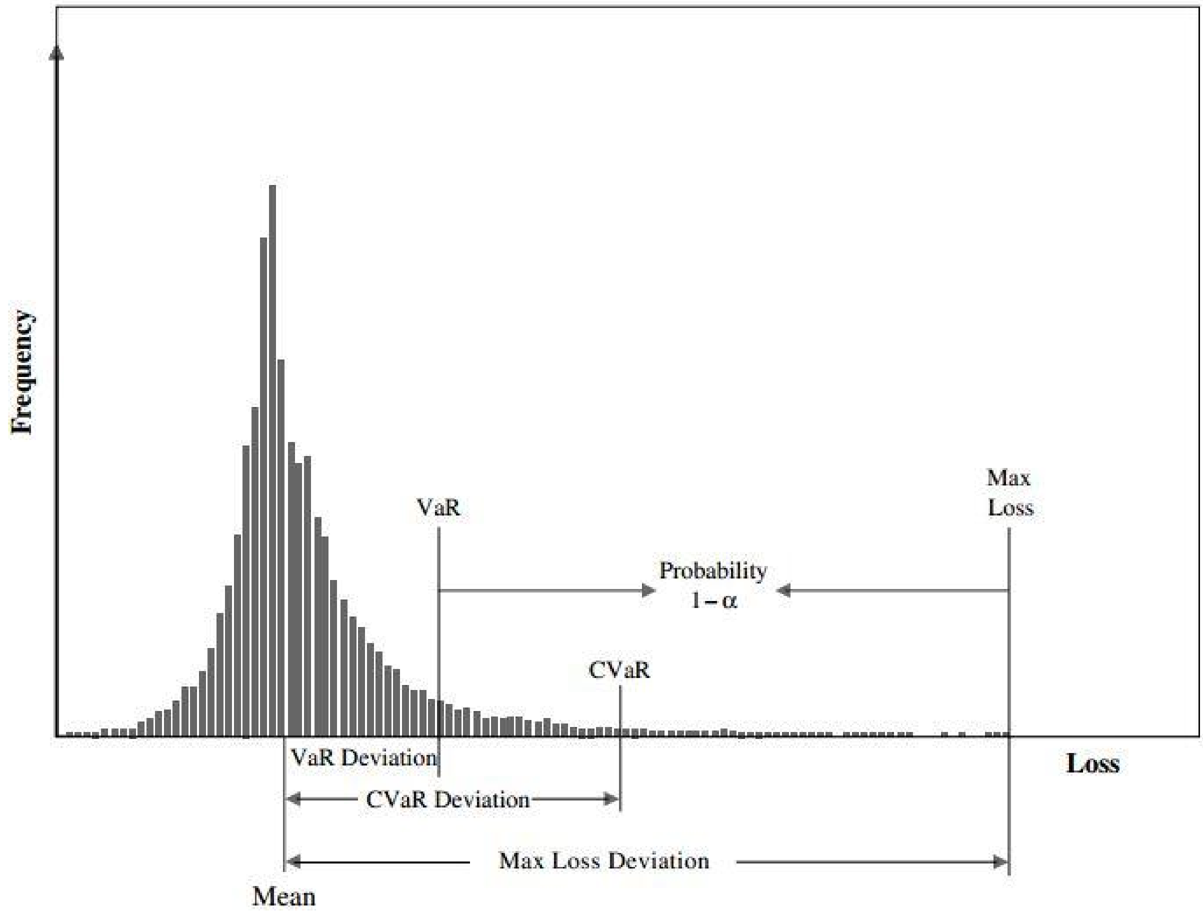

Figure 3.2 A loss distribution (Sarykalin, et al., 2008)

By considering the wind power participant's willingness to avoid risks it is possible to solve optimal risk-averse bid, as it is done in (Jónsson, et al., 2012) and (Bourry, et al., 2008). The utility function can be formulated as it is done in (Chen, et al., 2008):

$$\widetilde{W}^{(S)} = arg \max_{\tilde{E}} \left\{ (1-\lambda)\mathbb{E}\left[C_k^{(\uparrow/\downarrow)}\right] + \lambda \mathrm{CVaR}_\alpha \left[C_k^{(\uparrow/\downarrow)}\right] \right\} \tag{3.27}$$

where the parameter $\lambda, 0 \leq \lambda \leq 1$ describes the wind power participant's willingness to take risks. Total risk-aversion can be obtained when $\lambda = 1$, and when the λ equals zero the strategy returns back to the EUM bidding strategy, which is risk-neutral.

Assuming that the CVaR_α value can be found from the left tail of a loss distribution, it is possible to make a general equation for CVaR_α, equation (3.28)

$$CVaR_\alpha(X) = \eta_\alpha - \frac{1}{\alpha}\mathbb{E}[\max\{(\eta_\alpha - X), 0\}] \tag{3.28}$$

where η_α equals Value-at-Risk with a confidence level, α

$$\eta_\alpha = F_X^{-1}(\alpha) \tag{3.29}$$

It is possible to show that there is an analytical solution for CVaR_α when objective is to maximize revenue function. However, then it must be assumed that the balancing prices are fixed and not stochastic (Dent, et al., 2011). However, when the prices are stochastic, solving of the analytical equation for optimal bid might not be possible, as it was discussed in (Jónsson, et al., 2012).

3.2.4 *Including the Elspot price risk to the risk aversion strategy*

When using the risk-aversion strategy presented in the previous chapter, it is not actually the same when the participant minimizes balancing costs or maximizes revenue. Only the revenue maximization strategy includes the price risk of Elspot-prices. The expectation of revenue function can be made explicit

$$\mathbb{E}\left\{\rho_k|\widetilde{W}_k^{(S)}\right\} = \widetilde{W}_k^{(S)}\hat{\pi}_k^{(S)} + \hat{\psi}_k^{(\uparrow)}\int_0^{\widetilde{W}^{(S)}} \left(W_k - \widetilde{W}_k^{(S)}\right) d\mathbb{P}_{W_k} \\ + \hat{\psi}_k^{(\downarrow)}\int_{\widetilde{W}_k^{(S)}}^{W^{max}} \left(W_k - \widetilde{W}_k^{(S)}\right) d\mathbb{P}_{W_k} \qquad (3.30)$$

where $\hat{\pi}_k^{(S)}$ is the expectation of Elspot-price. By taking the example, which was presented in (Jónsson, et al., 2012) it is possible to understand the difference on maximizing the revenue or minimizing the balancing costs by using the CVaR_α. Let's assume that for a given hour there are 10 equally probable scenarios of wind power production

$$[w_{s1}\ w_{s2}\ \dots w_{s10}] = [0\ 1 \dots 9]\ MWh/h \qquad (3.31)$$

Thus, the probability, p that production is one of the values equals 10 %. Also, assuming that up- and down-regulation are equally probable and the prices are fixed such that

$$\pi^{(S)} = 20, \pi^{(\uparrow)} = 30, \pi^{(\downarrow)} = 10 \Rightarrow \psi^{(\uparrow)} = \left|\psi^{(\downarrow)}\right| = 10 \qquad (3.32)$$

Finally, if it is assumed that α=0.1 then it is possible to calculate, which bid maximizes CVaR_α when the utility function is minimizing balancing costs or maximizing revenue. The EUM bid on the previous example, and as well the bid, which maximizes the expected revenue and minimizes the balancing costs, is 4.5 MWh/h. However, on the revenue formulation CVaR_α is maximized at 0 MWh/h. Why the bid that maximizes CVaR_α zero on revenue formulation when the balancing cost formulation the same bid is 4.5 MWh/h. The balancing cost formulation considers production risk while the revenue formulation considers both the price and production risk together. Therefore, while the down regulation price is positive, as in the example, the positive revenue can only be achieved by bidding 0 MWh/h on the Elspot-market. Thus, the CVaR_α on revenue formulation is 0 MWh/h. On the balancing cost formulation the price risk is not included and thus the minimum risk can be obtained by bidding 4.5 MWh/h to the Elspot-market. The main question, which was also discussed in (Jónsson, et al., 2012) is that, which formulation should be preferred. The revenue formulation illustrates wind power participant's true risk of losing money. However, the bidding behaviour differs greatly since bidding on balancing cost formulation reflects more to the forecasted energy production than bidding on revenue formulation.

The choice of the formulation method could be looked from another direction. Since the CVaR_{α} is a coherence risk measure, the sub-additive nature of it requires that the risk of combined risk (Elspot and balancing market) must be lower than adding the risk of Elspot and balancing market.

$$\mathrm{CVaR}_{\alpha}\left(\rho_k\right) \leq \mathrm{CVaR}_{\alpha}\left(\rho_k^{(S)}\right) + \mathrm{CVaR}_{\alpha}\left(\rho_k{}^{(\uparrow/\downarrow)}\right) \tag{3.33}$$

One can notice that the $\mathrm{CVaR}_{\alpha}\left(\rho_k^{(S)}\right)$ is a function of energy production at time *k* and the corresponding Elspot-price at that same hour, which both are terms that WPP cannot influence. Thus, from the risk control point of view it would make more sense to emphasise the latter term, $\mathrm{CVaR}_{\alpha}\left(\rho_k{}^{(\uparrow/\downarrow)}\right)$. Therefore, using this reasoning one could prefer more the balancing cost formulation instead of revenue formulation.

3.3 Bidding in the Elbas-market

In the previous chapters trading in day-ahead market was considered. Trading at the Elbas market could provide additional value managing the risks, which are caused by the uncertain production and balancing prices at a delivery hour. The Elbas market is continuous market, where the electricity is traded as *first come first serve* basis. The first trade where the participants' sale and purchase bid counter leads to the bilateral trade between the participants. This kind of pricing mechanism is denoted as *pay as bid pricing*. In (Bourry & Kariniotakis, 2009) method for bidding in sequential day-ahead and intra-day markets is presented with risk aversion strategy. The method is based on assumption that the decisions on day-ahead and intra-day are made separately. Also a model for intra-day prices was created in that study. In (Morales, et al., 2010) complete method for bidding in the day-ahead and intra-day markets is presented. **The main question is still that is there any sense at the current market structure to bid in Elbas-market.**

3.4 Final trading scheme

Combining the previous mentioned steps it is possible to create a scheme how a wind power participant trades energy, Figure 3.3. A proper advanced bidding method requires four different forecast models and two modules with decision making capability when adjusting bids in the Elspot- and Elbas- markets. There are many requirements for the forecast models, and they require a lot of historic data from the electricity markets and measurements from wind turbines. The required forecast models are: Wind energy (day-ahead, intra-day), Elspot, Elbas, and forecast model for balancing prices and regulation direction. Models' forecast horizon varies from one hour, up to more than 36 hours ahead. Also, in order to use the EUM bidding strategy presented in the chapter 3.2.1, the forecasts must also include the probability distributions.

The two decision making points are presented with blue colour in the Figure 3.3. One of the decision making strategies in Elspot trade is presented in the chapter 3.2. However, it is possible to create multiple different strategies depending what is the method how the risk is determined and what is the participant's willingness to take risk. Probably, if a wind power participant is a large distribution company its bidding strategy differs from a small privately owned wind turbine company, which does not have the same capability to withstand large losses in energy market. Decision strategy at the Elbas-market is not studied in this report, since the price formulation of Elbas-market is very uncertain.

The basic idea behind the scheme presented in the figure below is that from the turbines, wind power participant measures at least the power production and uses it in day-ahead forecast model together with other appropriate inputs. After the forecast has been made, the wind power participant can use its bidding strategy with the help of Elspot-price forecast and balancing price forecast. The result of the bidding strategy is a set of day-ahead bids, which reflect the bidding strategy of the participant. As the bids are commenced to the Elspot-market, the participant can start placing intraday bids to the Elbas-market. As the delivery hours come closer, wind power production in a delivery hour can be updated by using the updated Numerical Weather Predictions, NWP. When the Elspot-prices are published it is possible to update balancing price forecasts and the participant can thus submit sale or purchasing bids to the Elbas-market, which again reflect the strategy of the participant. Since, trading in the Elbas-market requires counterparty; there is no guarantee that the bids will be accepted. After the intra-day bids are submitted and the delivery day has ended, actual energy deliveries are compared to the contracted values and the imbalances are dealt with the corresponding balancing prices.

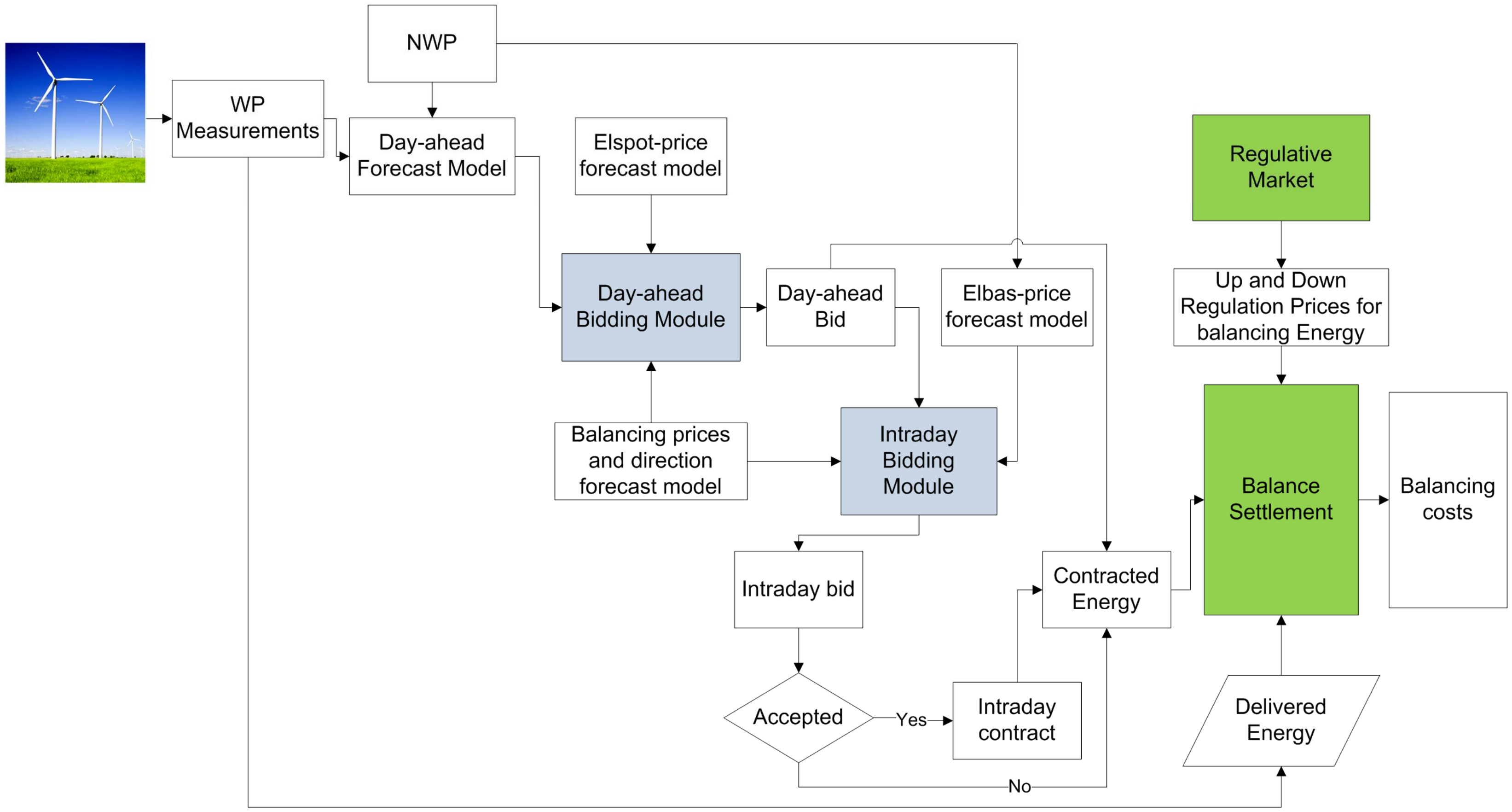

Figure 3.3 Trading scheme in the Spot-market

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