Business models for battery storages
-
Trading of electricity on European Electrictiy Exchange (EEX)

Thorben Doum, B. Eng

Cologne University of Applied Sciences
F07, Institut für Elektrische Energietechnik, Betzdorferstr. 2, 50679 Köln, Germany
tdoum@fh-koeln.de
supervised by Prof. Dr. Eberhard Waffenschmidt, eberhard.waffenschmidt@fh-koeln.de

Abstract:
This paper deals with the simulation of a battery energy storage on the European Electricity Exchange. It is examined, whether there is a possible mode of economic operation for a battery energy storage system (BESS) on the intraday market, buying energy on low and selling energy on high electricity costs. An algorithm based on electricity prices creates a real schedule as a function of different interval lengths for the battery storage. The profit from dealing with 1 MW on the intraday market for one year at an interval length of 24 hours is about 540.000 Euro. In comparison to a sufficiently large battery storage, the costs for the BESS are about 620.000 € per year when looking ahead on an operating time of 20 years.

Keywords:
battery energy storage system, European Electricity Exchange (EEX), electricity prices, algorithm, intraday market

1 Introduction

Driven by the expansion of renewable energies and the consequent displacement of electricity from conventional power plants, the energy transition involves a massive reconstruction of the existing power grid and we observe a change from a central to a decentral energy generation.
In decentralized energy supply electrical energy comes from smaller installations, such as photovoltaic or wind turbines. In the event, that the sun does not shine and the wind does not blow, there is the necessity of electrical energy storages and hence energy storage will become more and more important to compensate these fluctuations. Another reason for the investigation into business models for battery storages is the continuous decrease of battery prices.
First we examine whether it is economical to act with a battery storage on the intraday market. A second part - done by Jakob Bähr - deals with the efficiency of energy storages examined on the primary frequency control market [1].

2 European Energy Exchange

The European Energy Exchange, also called EEX, is the leading energy exchange in central Europe and it is located in Leipzig.
It operates spot and derivative markets for energy and energy related products and includes more than 200 trading member firms from 24 countries [2]. In 2012 in Germany more than twice as much electricity was traded on electricity exchange than was consumed. The stock market is open to everyone, who wants to sell energy on the market and who meets the requirements.
On the derivative market of EEX in Leipzig, participants can trade power contracts (weeks, months, quarters, years) up to 6 years ahead [2].
The spot market, located in Paris, serves as a trading center for short-term electricity, available within 1-2 days and organizes the trading of electrical power, which was not sold on the derivatives market. It includes intraday and day-ahead market.
The regulating or balance power market keeps balance between total generation and consumption of power real time (Compare Figure 1).

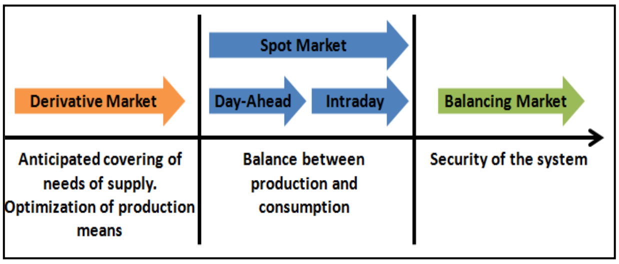

Figure 1:Time line of the power market [3]

2.1 Intraday market

The intraday market organized by continuous trading of electrical energy is an efficient and interesting solution for producers and consumers to react on variations between the forecast and the real schedule. Contracts can be traded one day before up to 45 minutes before physical fulfillment, with the possibility to trade blocks of either 15 minutes or one or several hours. The minimum volume increment is 0.1 MW [4].
Intraday markets allow to trade energy up to 45 minutes ahead of delivery, which provides a high level of flexibility, welcomed by market players who trade both, renewable and conventional energy.
Figure two shows the intensity of electricity prices on intraday market for the year 2013 for each day at any hour [5].
The prices vary between -84,88 €/MWh and 163,44 €/MWh. In simplified terms, within these two price pairs, it is possible to make a profit of 248 €/MWh:

$$\text{Revenue} = C_{\text{Sell}} - C_{\text{Buy}} = 163{,}44\frac{€}{\text{MWh}} - -84{,}88\ \frac{€}{\text{MWh}}$$

$$\mathbf{Revenue} = \mathbf{248{,}32}\ \frac{€}{\mathbf{MWh}}$$

Note that the price of electricity is very low at night (10.00 pm to 06.00 am) and at weekends. Moreover the price of electricity is more expensive at the beginning and at the end of the year than it is in summer. Negative electricity prices are reached for about 100 hours in 2013. The combination of high wind power or photovoltaic production in conjunction with inflexible conventional power plants (for example coal power plants) and a low demand lead to negative prices at the EEX.
Forecasts for the intraday prices are created with the help of information about weather, loads, types of day or session. These forecasts will be used to create a possible road map for the battery.

3 Simulation model

The following section deals with the simulation of a battery energy storage on the European Electricity Exchange and was developed in LabVIEW. In order to construct a battery energy storage system as a function of the electricity prices at the European Electricity Exchange, it is important to identify hours as charging or discharging hours. An economic schedule of the BESS will be created in consideration of energy losses and electricity prices.
In the simplest form the algorithm is given by:

- Battery is charged on low electricity costs
- Battery is discharged on high electricity costs

In a first step we identify hours, where revenue for discharging the battery is higher than costs for charging the battery are.
Electricity prices are sorted ascending and descending for different intervals (for example, one day, three days or one week. Using these sorted price pairs makes it possible to create a real schedule for different interval lengths by creating price pairs - the cheapest one to the most expensive one - as long as prices for discharging the battery are less than or equal to the revenue for charging the battery as shown in the equation below:

$$\frac{C_{\text{Buy}}}{\eta_{\text{charge}}} \leq C_{\text{Sell}} * \eta_{\text{discharge}}$$

The final price pair defines the price limits for charging and discharging the BESS. Times for electricity prices between these two limits are defined as downtime (no charging or discharging of the BESS). Based on the determined limits BESS is simulated according to the electricity price curve. Due to the limited capacity of the battery it is possible that in hours with high or low electricity prices the battery cannot be charged or discharged because of a full or empty memory. Following capture analyzes how large the capacity should be as a function of the interval length.

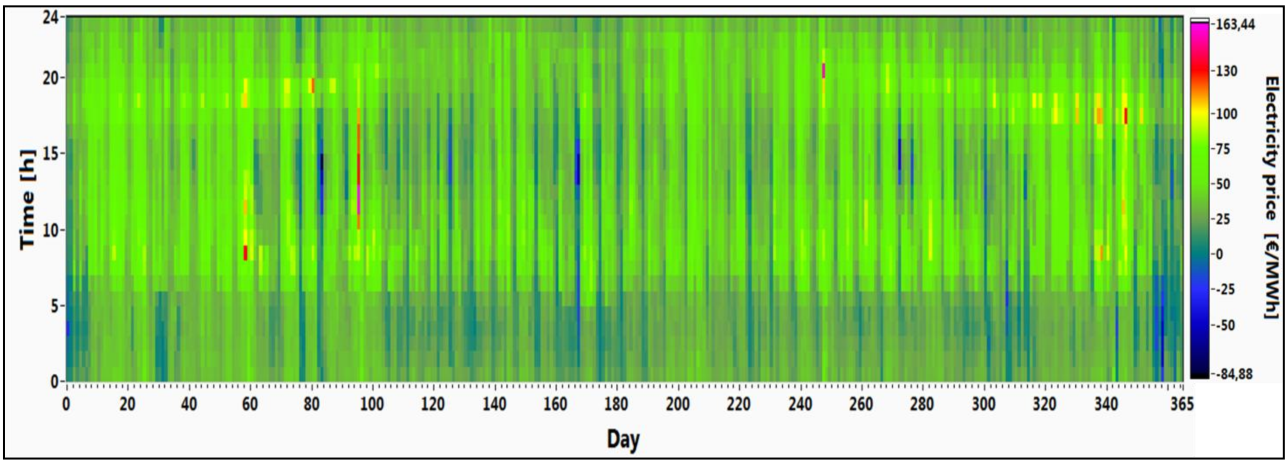

Figure 2: Intensity of electricity price for the intraday market

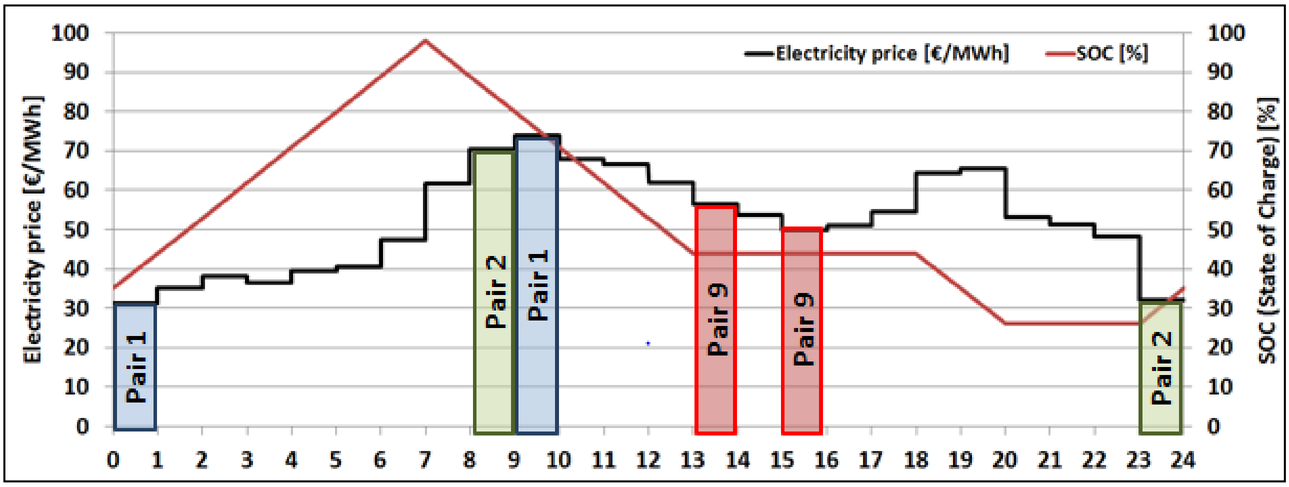

Figure 3: Electricity price and battery schedule

Figure 3 shows an example of electricity prices in €/MWh (black) and battery schedule (red) as the function of an interval length of 24 hours (one day). The example identifies reasonable prices especially during the night. For this reason, the battery is charged in the first seven hours of the day and between 11.00 pm and 12.00 pm. The BESS is discharged between 07.00 am and 01.00 pm and between 06.00 pm and 08.00 pm. During the rest of the time the battery will not be charged or discharged. From price pair 9 you will see that the revenue for discharging the battery is not higher than the costs for charging the battery are, so there is no profit (compare fig. 3).

For this special day as a result there are 8 price pairs where a profit is achieved and the revenue is 231.45 Euro when the BESS is charged or discharged with 1 MWh.

To keep the battery capacity as small as possible, the initial condition for the state of charge (SOC) is 35 %. The SOC is the same at the end of the interval as it is at the beginning because due to building price pairs, there are equal numbers of hours where the battery is charged or discharged.

Figure 4 shows the total revenue of BESS as a function of interval length for 1 MW charging power and an infinitely large memory.

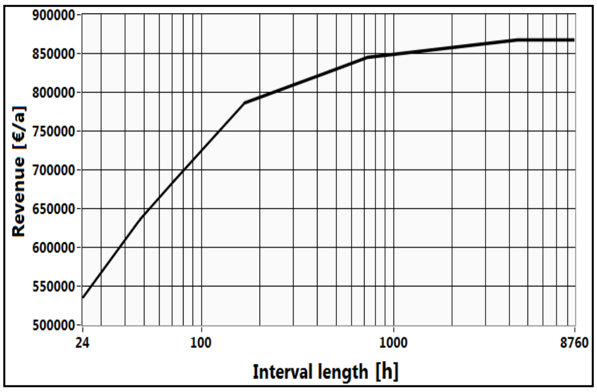

Figure 4: Revenue as a function of interval length

The annual profit for an interval length of 24 hours is 540.000 Euro.

The maximum revenue of 870.000 Euro is reached at an interval length of 8760 hours (1 year). An interval-length up to 100 hours will increase revenue drastically because of very low electricity costs especially at the weekends. Longer interval lengths lead to higher profit but require larger battery capacities.

Figure 5 shows the battery capacity as a function of interval length to achieve one hundred percent availability for the year 2013. In this case the initial state of charge of the battery is 50 %. It is, however, difficult to make a prediction for the development of the electricity prices at the beginning of the year. With an interval length of 24 hours the battery capacity has to be 17 MWh. Selecting a capacity of 10 MWh and an interval length of 24 hours, you will already experience a non-availability over 300 hours.

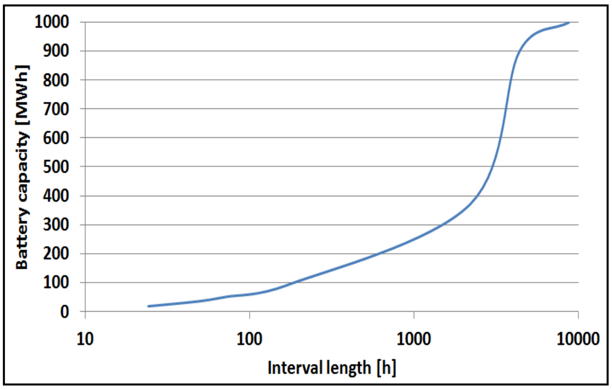

Figure 5: Battery capacity as a function of interval length

Figure 5 shows that for longer interval lengths there is need for extreme large battery capacities. In order to achieve a one hundred percent availability with an interval length of 8760 hours, a battery capacity of 1000 MWh is required.

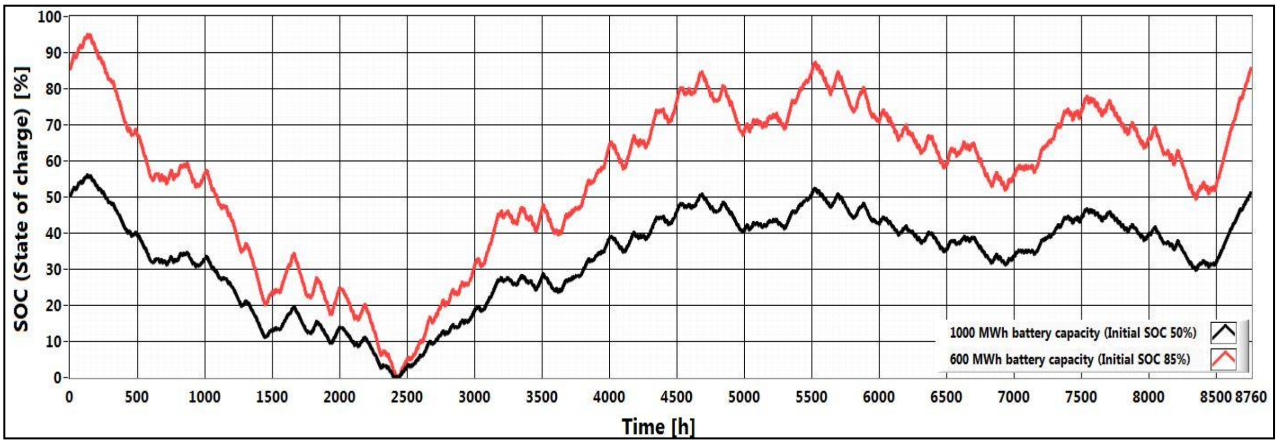

Figure 6: Battery SOC with an interval length of 8760 hours

Figure 6 shows the SOC of the battery with an interval length of 8760 hours for two different initial states of charge. Based on this illustration, it can be shown that electricity price depends on seasons. On the first and last days of the year electricity prices are very low and the battery is charged. This case can mainly be attributed to the extended production break over the Christmas/ New Year holiday period. During the first quarter of the year the battery is almost completely discharged, due to very high electricity prices. In mid-April, the BESS reaches its lowest point at 2500h. Through this, the battery capacity is determined. High input of photovoltaic power starting in April and continuing during the summer months (up to 37 GW in Germany) result in a low electricity price on the stock market and the battery is charged most of the time. At the end of summer the battery is discharged (5500h - 7000h). We may conclude that there was low production of renewable energies. Charging the battery at the beginning of October (7000h) can be explained by a high input of wind power.
The red curve shows an initial state of charge of the battery of 50 %. If it is possible to know the course of electricity prices at the beginning of the year, the capacity of the BESS can be stay much smaller. As figure 6 clearly shows, the battery capacity can be reduced from 1000 MWh to 600 MWh, if the initial state of charge is increased to 85 %.
The development of electricity price depends on many different factors, that is why it is not possible to give a statement at the beginning of an interval and the initial state of charge is chosen at 50 % for the simulation, but keeping in mind that there is a potential to save costs.

4 Economics

In the current situation the battery capacity can be seen as the main cost driver. The costs of a lithium-ion battery is estimated with 700.000 €/MWh for the capacity and additionally 100.000 €/MW for power electronics [6].
For this reason, the battery energy system is accepted with a capacity of 10 MWh and a charge power of 1 MW. With an interval length of 24 hours and a capacity of 10 MWh, there is a non-availability over 300 hours for 2013. Optimizing the battery schedule trough to individual adjustment of the SOC or leaving out price pairs with low margin, the non-availability can be reduced to a minimum.
For longer interval lengths, the required capacity and subsequently the costs for the battery storage are too much, so that an analysis does not make any sense.
The costs of a battery energy storage are:

$$c = 10\ \mathrm{MWh} * 700.000\ \frac{€}{\mathrm{MWh}} + 1\ \mathrm{MW} * 100.000\ \frac{€}{\mathrm{MW}}$$

$$\mathbf{costs_{invest}} = \mathbf{7.100.000}\ €$$

By means of the annuity factor, the total costs of the battery system are calculated, which are distributed over the operating time.

$$\mathrm{ANF_{n,i}} = \frac{(1+\mathrm{i})^{\mathrm{n}} * \mathrm{i}}{(1+\mathrm{i})^{\mathrm{n}} - 1} = 0{,}08718$$

with n: number of terms
n = 20 years
i: per term interest rate
i = 6 %

Thus, the costs per year of a battery can be calculated at an operating time of 20 years. As can be seen from figure 4, the annual profit for an interval length of 24 hours is 540.000 Euro.

$$\mathbf{c_{annual}} = \mathbf{7.100.000}\ € * \mathbf{0{,}08718} \approx \mathbf{620.000}\ €$$

$$\mathbf{Revenue_{annual}} \approx \mathbf{540.000}\ €$$

5 Conclusion and outlook

In the light of the above considerations it is at present not profitable to participate on the intraday market with a battery energy system.

For several reasons, mentioned below, trading electricity on the intraday market can nevertheless become economical in the future.

Battery prices are constantly decreasing and the costs for a lithium-ion battery are in this economical calculation on a comparatively high level (700.000 €/MWh for the capacity and additionally 100.000 €/MW for power electronics). According to a study conducted by McKinsey & Company battery prices will reach 200 €/kWh by the year 2020 [7].
On the intraday market the expansion of renewable energies leads to more fluctuation concerning the price of electricity and the margin between the price pairs will become larger and thereby the profit will increase.

Therefore, it can be in the future, that the costs for a battery energy system fall down and the revenue increases, so that it is possible by buying energy on low and selling energy on high electricity costs to earn money.

6 References

[1] Jakob Bähr, "Business models for battery storages - primary frequency control market" *Cologne Institute for Renewable Energy*, FH Cologne, 2014.

[2] 28.09.2014: www.deutsche-boerse.com/mda/dispatch/en/listcontent/gdb_navigation/mda/200_market_data/200_derivatives_market/Content_Files/derivatives_market_products/mda_sp_eex.htm

[3] Own creation in accordance with (27.08.2014): http://en.wikipedia.org/wiki/EPEX_SPOT

[4] 10.08.2014: http://www.epexspot.com/en/product-info/Intraday/germany

[5] 15.04.2014: http://www.epexspot.com/de/

[6] Maciej Swierczynski, "Primary Frequency Regulation with Li-ion Battery Energy Storage System" ECCE Asia 2013

[7] Prof. Dr. Eberhard Waffenschmidt, "Dezentrale Strukturen elektrischer Netze - Elektromobiltät"