Business models for battery storages - Primary frequency control market

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***Abstract* - This paper deals with the simulation of a battery energy storage system (BESS) to take part on the primary frequency control market. Providing primary reserve on the frequency control market could be a reasonable solution for a BESS, working with a non-critical frequency window to restore an optimum battery state of charge (SOC). Higher use of balancing power in a non-critical frequency window leads to reduced battery capacity and further to reduced total costs. The revenue for selling ± 1 MW of primary reserve in Germany for one year is about 150.000 €. Compared with this, annual costs for the BESS, looking forward on a 20 year operating time, are about 70.000 € per year.**

***Index Terms* - primary reserve, battery energy storage system, frequency control market**

I. INTRODUCTION

The continuous change of central power generation to decentral power generation and further expansion of renewable energies will provide us with new challenges, creating a sustainable and secure energy system. With this changes, new technologies can be derived which create new markets and business models. Uneconomical operation of conventional power plants and the shutdown of nuclear power plants until 2022 [1] lead to new technologies for system security. In this context energy storages are a forward-looking solution for integrating renewable energies into the existing energy system.

High efficiency and decreasing prices will move BESS continuously in foreground. Especially providing system services like primary-, secondary-, and tertiary frequency control or operating on electricity exchange are new possibilities for BESS, due to fast power supply within milliseconds.

This paper will give an impression of operating a BESS on the primary frequency control market, using a non-critical frequency window of ± 20 mHz to restore an optimum battery SOC.

Second part of this paper, which is written by Thorben Doum, shows the operation of a BESS on the European Energy Exchange (EEX).

II. FREQUENCY CONTROL MARKET

The frequency control market is separated in three different submarkets:

- Primary frequency control reserve
- Secondary frequency control reserve
- Tertiary frequency control reserve

Figure 1 shows a schematic diagram of the various frequency control types, chronologically used.

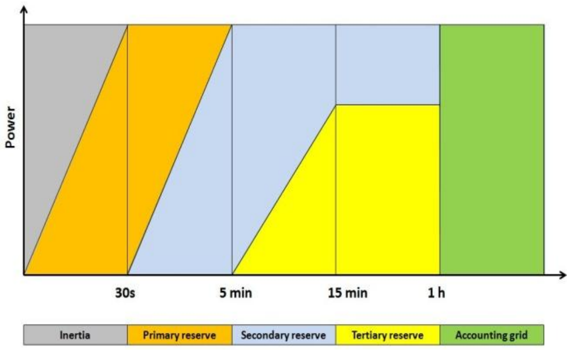

Figure 1: Chronologically used frequency control types [2]

In the time domain of milliseconds, frequency deviations are caught by the moment of inertia from rotating masses in the total system of the ENTSO-E.

Rotating masses are able to damp frequency deviations for a short time in case of generation losses and provide time for the following frequency control types to stabilize grid frequency.

II.1 Primary frequency control reserve

ENTSO-E supports ± 3000 MW of primary reserve, ± 600 MW is provided by Germany. The total primary reserve has to be activated on frequency deviations of ± 200 mHz within 30 seconds for at least 15 minutes. The time period providing primary reserve contains one week with a minimum volume of ± 1 MW [4].

Operating on primary frequency control market obligates to provide both, positive and negative primary reserve. There is no choice of operation direction, like it is on secondary frequency control market.

Working with a single system allows security arrangements with other prequalified systems which are not providing primary reserve for the same week, to get 100 % availability for the whole period. Operating a pool of smaller systems to fulfill an amount of primary reserve allows changing constellations of this pool on the beginning of each ¼ hour.

Payment on primary frequency control market is for providing primary reserve per MW. There only exists a reserve price.

II.2 Secondary frequency control reserve

Objective of the secondary frequency control reserve is to repatriate frequency on the nominal value of 50 Hz. Activation time is determined on 5 minutes. The minimum volume, operating on secondary frequency control market, is 5 MW with a volume increment of 1 MW, for arbitrary directions (positive or negative reserve). [4]

Time period for one week is separated in the following table [4]:

Low tariff	
Monday- Friday	0:00am - 08:00am 20:00pm - 24:00pm
Saturday-Sunday	0:00am - 24:00pm
High tariff	
Monday- Friday	08:00am - 08:00pm

Table 1: Separation of high and low tariff on secondary frequency control market

Payment on secondary frequency control market consists of payment for reserve per MW and additionally of payment for electrical work on retrieval. Usually reserve prices are much lower than prices for electrical work. Retrieval frequency on secondary frequency control market depends on the position of the operating system in the merit order list.

II.3 Tertiary frequency control reserve

Time period for tertiary reserve is announced daily and consists of negative and positive reserve in 4 hour blocks. Task of tertiary reserve are longer term frequency deviations after 15 minutes. The minimum volume, operating on tertiary frequency control market, is also 5 MW with a volume increment of 1 MW. As on secondary frequency control market, payment consists of reserve per MW and electrical work on retrieval. [4]

III. SIMULATION MODEL

Following capture deals with the simulation of the BESS for primary reserve and was developed in LabVIEW.

III.1 Algorithm

The algorithm of the BESS power management is based on frequency measurements for a time period of one week which are resolute every second. Accordingly, there exist about 600.000 measured frequency values for the period of one week.

In the simplest form the BESS is charged when frequency exceeds 50,02 Hz and is discharged when frequency falls below 49,98 Hz. Frequency deviations of ± 20 mHz don’t cause the BESS to provide full primary reserve immediately, rather it follows a linear power increase. This is shown in figure 2.

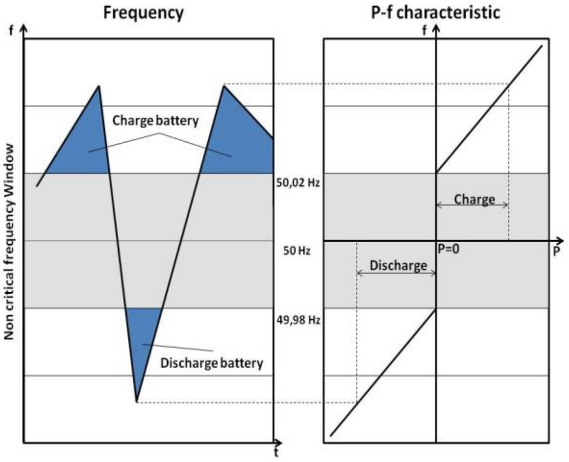

Figure 2: P-f characteristic of the BESS [6]

On the left hand side of figure 2, charge and discharge times for the BESS are shown. Frequency deviations > 20 mHz lead to a linear increase of power in the relevant direction, as shown on the right hand side of figure 2.

The power increase is determined on 1 % of P_n (P_n = primary reserve) per mHz frequency change. Therefore, frequency deviations of e.g. 50 mHz lead to a use of 30 % of primary reserve in this simulation (50 mHz – 20 mHz window).

III.2 Frequency influence

Upper area (1) of figure 3 shows a frequency profile for the period of one week from 09.06.2014 to 16.06.2014. The non-critical frequency window is marked in red. There are only two frequency deviations outside of ± 100 mHz within this week. A frequency deviation of ± 200 mHz, which requires 100 % of primary reserve, was never reached through the year 2005 [5]. Frequency deviations occur due to forecast changes, grid errors or power plant failures. Especially forecast changes are the most important reason for frequency deviations on every full hour.

Since increase of renewable energies, weather forecasts have become more important and take a huge influence on grid frequency.

III.3 Balancing power

Within these limits, the BESS can use a low amount of power, depended on provided primary reserve, to restore an optimum state of charge. This low amount of power is called “balancing power”. In this simulation the BESS power management idle the battery SOC every time on 50 % when frequency is in the non-critical window. Lower area (2) of figure 3 shows the variation of battery SOC on different balancing powers. These curves are based on a primary reserve of 1 MW with a BESS capacity of 1 MWh. Battery efficiency is determined on 90 %.

Operating the BESS with a balancing power (charge power and discharge power within non-critical frequency window) of 1 % (black curve) leads fast to an empty or full BESS, depending on primary reserve retrieval. If balancing power is determined on 5 % (red curve) load conditions are improved, but there are still times of non-availability because of an empty battery. Balancing power of 10 % (green curve) and 20 % (blue curve) lead to further improvements of the load conditions. The BESS is 100 % available within the chosen time period.

If battery SOC reaches still 0 % or 100 %, there is need of alternative power flow options, like described in chapter II.1. A single BESS can be secured of other prequalified systems, which are not providing primary reserve for the same week. Condition for this option is that the securing system is in the same accounting grid as the BESS. If there is an operation of the BESS in a pool (virtual power plant) it is possible that other systems provide primary reserve until BESS is available again [7].

Another possible way to retrieve the optimum SOC is to use electricity exchange or OTC market (over the counter - short term electricity trades). In this case, charge management and primary reserve delivery are energetically to separate. Declarations have to be done at least 15 minutes before physical fulfillment. In all cases of retrieving an optimum SOC, transmission network operators has to be involved in advance with an operating concept.

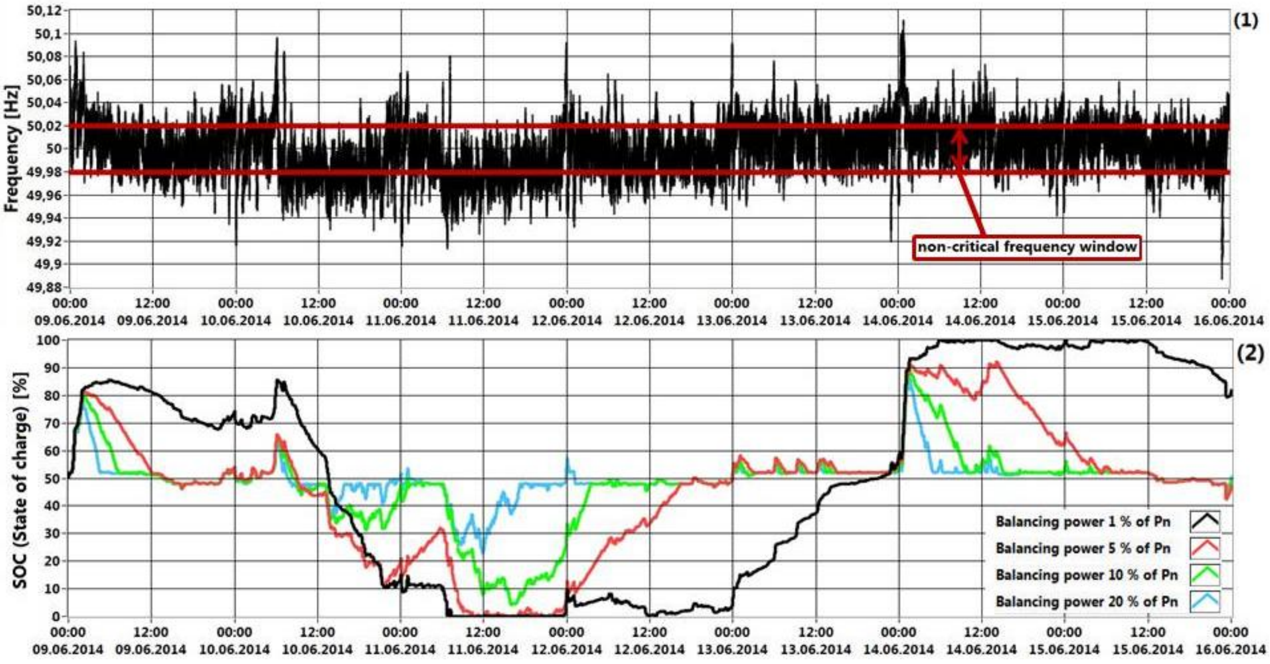

Figure 3: Frequency (1) and battery SOC with variation of balancing power (2) from 09.06.2014 – 16.06.2014

In case of selling and buying energy on the electricity exchange or on OTC market, figure 4 shows an example for quantities within the chosen time period of one week. These curves are also based on a primary reserve of 1 MW and a BESS capacity of 1 MWh, with an efficiency of 90 %.

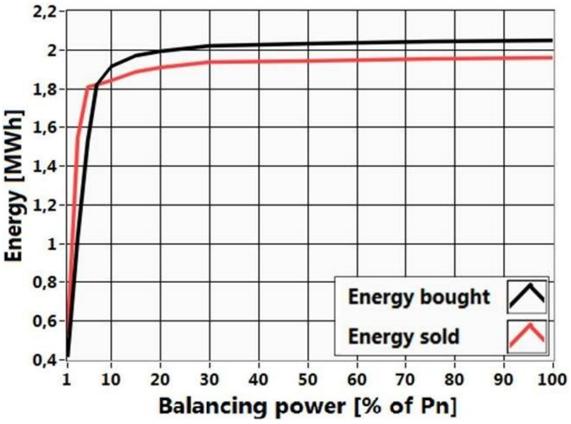

Figure 4: Sold and bought energy as function of balancing power

Sold energy (red curve) and bought energy (black curve) are represented as function of balancing power. The higher balancing power is chosen, the higher traded energy quantities are. As shown above, sold energy and bought energy are approximately on the same level. That means costs for charging the battery and revenue for discharging the battery can mostly be ignored.

IV. ECONOMICS

IV.1 Capacity reduction

Main cost driver in the actual situation is battery capacity, so there is need to reduce battery capacity as much as possible. Working with a variable balancing power can show how much battery capacity can be reduced. This illustrates figure 5.

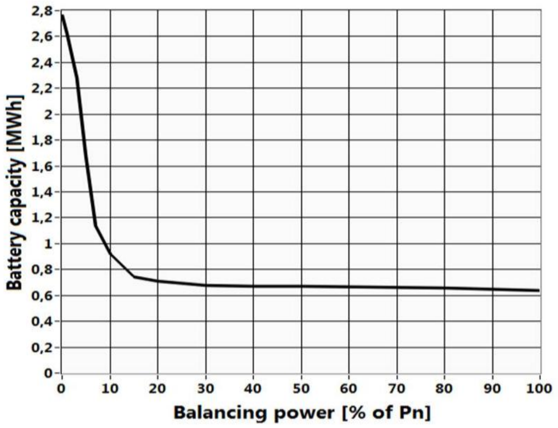

Figure 5: Capacity reduction as function of balancing power

In case of 0 % balancing power, which means battery SOC depends only on primary reserve actions, capacity has to be determined on 2,8 MWh to reach 100 % availability for the chosen time period of one week, with a primary reserve of 1 MW and battery efficiency of 90 %. Any other constellation of frequency measurements could impact the dimension of battery capacity, so there is no fixed value. The higher balancing power is chosen, the smaller battery capacity can stay, with a minimum capacity for the chosen period of about 0,6 MWh. The highest capacity reduction is reached on balancing powers between 1 % - 15%. Further increases of balancing power lead to insignificant reduction of the battery capacity. The best level of operating a BESS lies between 5 % - 20 % balancing power.

IV.2 Revenue

Looking back on the development of the power prices on primary frequency control market for the last four years, profit margin varies between 144.000 €/MW/year and 183.000 €/MW/year. In 2013 revenue for providing ± 1 MW of primary reserve amounts 154.000 €. This is shown in figure 6.

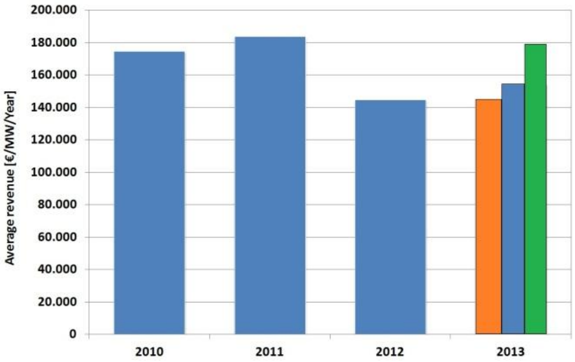

Figure 6: Development of total revenue on primary frequency control market [8]

Additionally to the average values in blue, minimum (orange – 146.000 €/MW) and maximum (green – 178.000 €/MW) revenue for 2013 is shown. Power prices are not fixed values within one announced week, rather they vary over the whole time period.

IV.3 Costs

Considering battery capacity as main cost driver, costs of 700.000 €/MWh (Li-ion battery) and additionally 100.000 €/MW for power electronics can be estimated [9]. Providing ± 1 MW of primary reserve on primary frequency control market with balancing power of 8 % leads to a battery capacity of 1 MWh for the examined time period of one week.

Annual costs for a time period of 20 years with a discount rate of 6 % are:

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

$$n = operating\ time = 20\ years$$
$$i = discount\ rate = 6\ \%$$

$$c_{invest} =$$

$$1\ MWh * 700.000 \frac{€}{MWh} + 1\ MW * 100.000 \frac{€}{MW}$$

$$= \mathbf{800.000}\ €$$

$$c_{annual} = 800.000\ € * 0.08718 \approx \mathbf{70.000}\ €$$

Annual costs for this example can be estimated on 70.000 €.
Increase of balancing power on e.g. 20 % can reduce battery capacity on 0,7 MWh. Annual costs for this case are reduced to 51.000 €.

V. CONCLUSION

Energy storages for stationary applications are becoming more and more attractive. Working with variable balancing powers can reduce battery capacity in high amount, which results in reduced total costs and better economics.
Costs of 70.000 €/year or even 51.000 €/year with reduced battery capacity, compared with an average revenue of 150.000 €/year lead to a reasonable solution, operating a BESS on the primary frequency control market. It is important that costs for securing the BESS or for alternative power flow options, which are difficultly to determine, are not considered in this paper. For exactly economical investigations, these costs have to be determined additionally.

A recently completed project of Yunicos shows that a BESS with a battery capacity of 5 MWh and provided primary reserve of 5 MW (**Samsung SDI guarantees a 20 year operating time**) nowadays is a possible solution [10].
Further decreasing battery prices will lead to more stationary applications on the frequency control market.

VI. REFERENCES

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