Economic Assessment of a battery storage system-Participation in control energy market in APG-control area

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Abstract: In this paper, a method for the operation of a small-scale electric energy storage unit (flow battery) at the energy exchange and control market in Austria is presented. An hourly sequentially linear optimization program is employed to determine the optimal charging and discharging strategy with consideration of battery parametres, existing market rules and energy/ power prices from 2010.

Keywords: Electric energy storage, Vanadium redox battery, Control market, Energy exchange market

1 Introduction

Generally, the main application of electric energy storage (EES) lies in storing energy and releasing it in other and certain time periods when its utilization is more beneficial from economical (or technical) point of view [1]. [2] mentioned three primary application fields for EES which can provide the stored energy at different time scales. The energy management (load levelling), bridging power (assuring continuity of service) and power quality/ reliability (voltage/ frequency control) build up the main application field

lds after [2]. On the other hand, the transmission and distribution systems currently or in the near future confront the variability of renewable electricity sources in countries/ areas with ambitious expansion of renewable energy sources. In this case, [3] suggests solutions for mitigating this volatility like expanding transmission and trade possibilities, improving forecasting of variable renewable electricity sources (VRES), increasing dispatchable back-up power generation, decoupling VRES generation from the grid as well as introducing EES. In this conjunction the EES can shift the generated energy from VRES to the periods with high demand or times with VRES production forecasting errors. It can also be used to restore the grid frequency (e.g. deviation happens from the normal value (50 Hz) because of demand fluctuations) in the control area. [4] evaluates sufficient bulk EES technologies for providing of regulation services in control areas BPA (Bonneville Power Administration) and CAISO (California Independent System Operator Corporation). The EES technology must be able to supply 10 MW for ones minute and thus, in each hour, the battery would be charged and discharged 15 times (131,400 of needed cycles within a year). The authors came to the conclusion that under mentioned technical conditions bulk flywheels, pumped hydro power plants and sodium-sulfur batteries are suitable for providing of regulation services. The vanadium redox battery (VRB) could not meet the requirements as bulk storage because of high capital costs due to low cyclic capability.

[1] made an economical comparison between bulk NaS battery and pumped storage plants under consideration of their technical constrains. The self-scheduling was introduced to maximise the storage profits due to their participating in energy, spinning reserve and regulation market. A weekly forecasting of energy, spinning reserve and regulation prices ($/MWh) build up beside the storage technical constraints the database for the calculation. They didn't consider market rules for spinning reserve and regulation like tendering and bidding period. [5] examines an small-scale EES (VRB- 100 kWh) application with the aim to maximise the profit by covering a household demand (3,200 kWh/yr) [6] and participating in the European energy exchange market. The results show that the distribution margin cannot cover the annuity of the investment and yearly maintenance cost of VRB. In this case study a 15 kW_p PV plant and a 1.5 kW wind plant are used as energy generation units.

Additionally, this paper focuses on deriving contribution margins of small-scale VRB (capacity: 100 kWh) due to its participation in the control energy market within the Austrian power grid (APG) control area as well as the energy exchange market. The maximisation of the contribution margin results from an hourly sequentially linear optimization (script in matlab) by considering of charging/ discharging profiles and existing control market rules (tendering periods). The configuration of the analysed system is shown in Figure 1. The EES acts as a separate unit at the mentioned markets and can use the PV generation [7] in its charging times if it is available. The VRES production covers at first the household demand. The residual amount can be fed into the EES and as a last option into the grid.

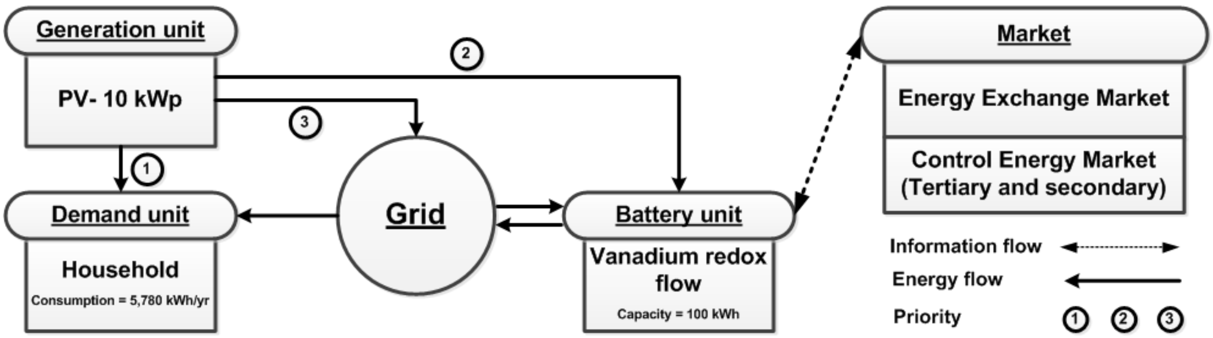

Figure 1: System configuration: Storage integration in combination with small-scale renewable plant (Photovoltaic)

The remainder of this paper is organised as follows: The next section provides an overview of development of called control energy in the APG- control area in 2010. The definition of battery operation schedule and related optimized mechanism (linear optimization) close this section. The third chapter describes the used data (market information). The results of denoted operation schedule for the battery are given in the fourth chapter, the fifth section provides a summary of the paper.

2 Battery operation schedule problem

2.1 State of ancillary service markets in APG- control zone

The EES will take part in energy exchange and control energy market. There are 3 different types of control energy in synchronous area of RGCE (Regional Group Continental Europe), primary, secondary and tertiary control. The primary control market was not considered. The aim of secondary control is the restoring the system's frequency to the target value. The activation of secondary control happens automatically [8]. This reserve is provided by generation units which are located in the control area where the frequency imbalance was originated. The continuing of frequency deviations (at least after e.g. 15 minutes) leads to activation of tertiary control (manually). The tertiary control release the secondary control reserve and take over the restoring of frequency in the certain control area.

The duration curves of the number of daily called positive control energy within different years in the APG control area are presented in Figure 2. The 15 minutes time resolution results in a potential of 96 possible calls within a day. The tertiary control faces a decreasing tendency in the period from 2006 until 2010 with only 78 call days. The amount of e.g positive tertiary control falls from 62.47 GWh in 2006 to 9.25 GWh in 2010 resulting in a percentage reduction of about 85 %. The secondary control calls appear with a different characteristic. Each day consist of several time periods with called secondary power. All analysed years enclose the same characteristics. The amount of e.g positive secondary control rises from 271.54 GWh in 2006 to 300.57 GWh in 2010

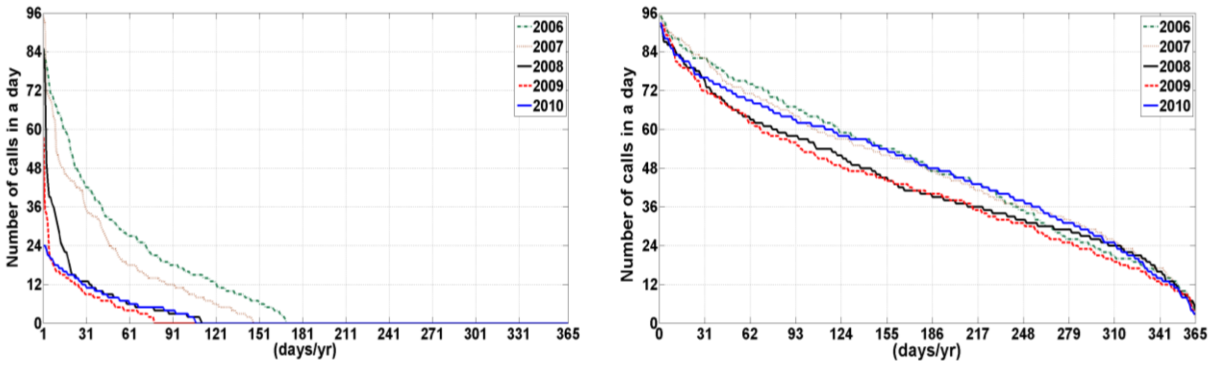

Figure 2: Number of calls of control energy within days in different years, Left: positive tertiary energy, Right: positive secondary energy (For a clear assignment of curves to the years, reader is referred to electronic version)

Currently, there only exists a market for tertiary control in the APG- control area with a weekly tendering period. The bids (separated in production and consumption) for tertiary control energy must be offered for time blocks 0:00 to 4:00, 4:00 to 8:00, 8:00 to 12:00, 12:00 to 16:00, 16:00 to 20:00 and 20:00 to 24:00. A market for secondary control is expected in 2012. For this new market the described tendering process like the one of the tertiary control market is assumed.

2.2 Scheduling of battery operation

The VRB positive characteristics consist of decoupled power and energy ratings, low self-discharge and moderate efficiency compared to other battery technologies [9]. Figure 3 shows the charging and discharging profile of a 100 kWh VRB, called CellCube, which is manufactured by GILDEMEISTER energy solution [10]. The VRB is operated between 10 and 83 % of its state of charge (soc). For participating in control markets (tertiary or secondary), the EES operator must ensure a certain and constant power during a time block (4 hour block). Therefore, the discharging profile shows a suitable area between 25 and 83 % of soc with a constant power of 10 kW (more than 10 kW * 4 h = 40 kWh). For ensuring of a certain and constant charging power over 4 hours (one time block), the charging power has been set to 10 kW between 10 and 61.38 % of soc.

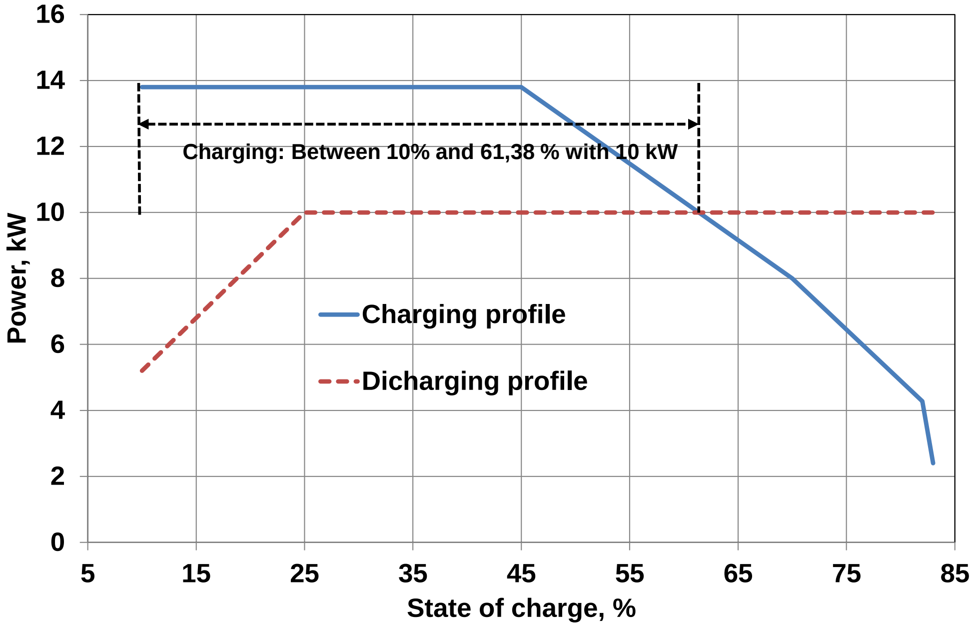

Figure 3: Charging and discharging profiles of VRB as a function of state of charge (soc)

Figure 4 shows the EES operation schedule by participating at the energy exchange and tertiary control market. For a fair comparison of the results the same operation schedule would be used in the case of participation of EES at the energy exchange and secondary control market. The figure in the background shows the number of calls of tertiary power per time period in 2010. The called positive control energy represents an incremental characteristic matching the increase in electricity demand between 08:00 to 12:00 and 16:00 to 20:00 o'clock. The decrease in demand between 00:00 and 04:00 o'clock shows itself by increases of called negative control energy. Hence, the mentioned time blocks, called control blocks, with considering of adapted battery charging/ discharging profiles build up the time periods where the battery ensures the delivery of a certain power as control power, if it is needed. If the EES (or EES operator) does not get a signal (automatically) or a phone call (manually) for delivering of control power in the mentioned control blocks (for each hour one signal), the battery will take part in energy exchange market. The other time blocks (04:00 to 08:00, 12:00 to 16:00 and 20:00 to 24:00 o'clock) defines areas which EES takes part in energy exchange market and can prepare its own capacity for the beginning of the control blocks. The chapter 2.3 provides the mathematical equations of described schedules in more detail.

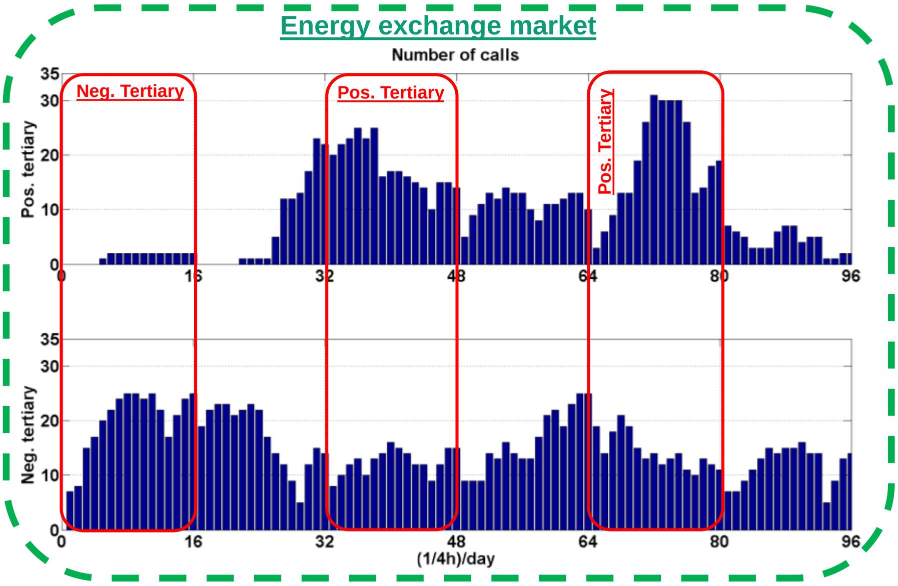

Figure 4: Battery operation schedule based on historical market information- participating in energy exchange and control energy market

2.3 Formulation of donated schedule based on hourly linear optimization

By assuming

- the battery own energy consumption in a range of 155 watt (pumps [11] and inverter energy consumption),
- the charging/ discharging efficiency from grid to battery (µG2B) or from battery to grid (µB2G) is about 95 %,
- charging and discharging characteristics (see Figure 3) and
- battery operation schedule (Figure 4),

a function of donated schedules in a year can be presented by (1) - (4). All the symbols are introduced in the appendix. The goal of the optimization is the maximization of EES (or EES operator) contribution margin due to its participation on energy exchange and control market.

$$S_{VRB}(t+1) = S_{VRB}(t) + P_{Charge,t+1}(S_{VRB}(t)) * \mu_{G2B} - P_{Discharge,t+1}(S_{VRB}(t)) - Own_{Consumption} \quad (1)$$

$$10\ kWh \leq S_{VRB} \leq 83\ kWh \quad (2)$$

$$\begin{cases} 2.4\ kW \leq P_{Charge,t}(S_{VRB}(t)) \leq 10\ kW \\ 5.2\ kW \leq P_{Discharge,t}(S_{VRB}(t)) \leq 10\ kW \end{cases} \quad (3)$$

$$\begin{cases} 65\ kWh \leq S_{VRB,Control\ market,Positive} \leq 83\ kWh \\ S_{VRB,Control\ market,Negative} \leq 21.38\ kWh \end{cases} \quad (4)$$

(1) describes the calculation of battery state which will be computed from the previous state, charging/discharging power as a function of previous state and battery own energy consumption. The state of charge, as shown in (2) can be varied between 10 and 83 kWh. The range of charging/discharging power variation results from Figure 3 and has been shown

as a function of battery state in (3). The battery state must fulfil a certain status or a status range at the beginning of the control blocks. So that, the EES-operator can ensure the delivery of control power in the demanded control blocks. The equation (4) shows the expected EES status for participating in positive control market at 08:00 and 16:00 o'clock as well as for participating in negative control market at 00:00 o'clock.

The revenues and expenses for EES (EES-operator) as a function of discharging/charging power, prices and efficiency from grid to battery and from battery to grid are presented in (5) and (6). The difference between revenues and expenses build up the contribution margin, which will be presented in result chapter.

$$\begin{aligned} revenues = {} & Control_{power,negative}\left(P_{Charge}, Price_{Power,neg}\right) \\ & + Control_{power,positive}\left(P_{Discharge}, Price_{power,neg}, \mu_{B2G}\right) \\ & + Control_{energy,positive}\left(P_{Discharge}, Price_{energy,pos}, \mu_{B2G}\right) \\ & + Exchage_{Market,energy\ sell}\left(P_{Discharge}, Price_{enegy}, \mu_{B2G}\right) \end{aligned} \tag{5}$$

$$\begin{aligned} expenses = {} & Control_{energy,negative}\left(P_{Charge}, Price_{energy,neg}, \mu_{G2B}^{-1}\right) \\ & + Exchage_{Market,energy\ purchase}\left(P_{Charge}, Price_{enegy}, \mu_{G2B}^{-1}\right) \end{aligned} \tag{6}$$

3 Data base

The EES characteristics, market rules as well as the energy prices at European energy exchange market (www.eex.com) from 2010 and mean value of energy and power prices in control market from 2010 build up the database for the calculation. The energy/ power prices for tertiary control refer to [12]. We assume that prices for secondary control after opening the market in 2012 will correlate with the existing prices in Germany. Therefore, the prices for secondary control are mean values from prime and secondary market prices, which occurred in Germany [13]. Table **1** gives an overview of the used energy and power prices for tertiary/secondary control in APG control area in 2010.

Table 1: Used power and energy price for regarded control power types ([12] and [13]**)**

		Power price €/MW/h	Energy price €/MWh
Tertiary	Positive	1	98
	Negative	5	4
Secondary	Positive	10.62	129.17
	Negative	13.46	19.40

4 Results

The results are given for participation of EES on tertiary and secondary control market, separately. Figure 5 shows the results for tertiary control market, which is also based on the system configuration of Figure 1. The outputs are subdivided in 3 different system designs, which can be described as:

- System design 1: optimized application of storage due to participating in control energy market (providing of negative and positive reserves) and energy exchange market (using of hourly price differences)
- System design 2: System design 1 including using of PV- production for covering of household demand
- System design 3: Consists of system design 1, 2 and application of PV- production for charging the storage, if secondary PV- production (main PV- production minus household demand) and battery charging time occur on the same time.

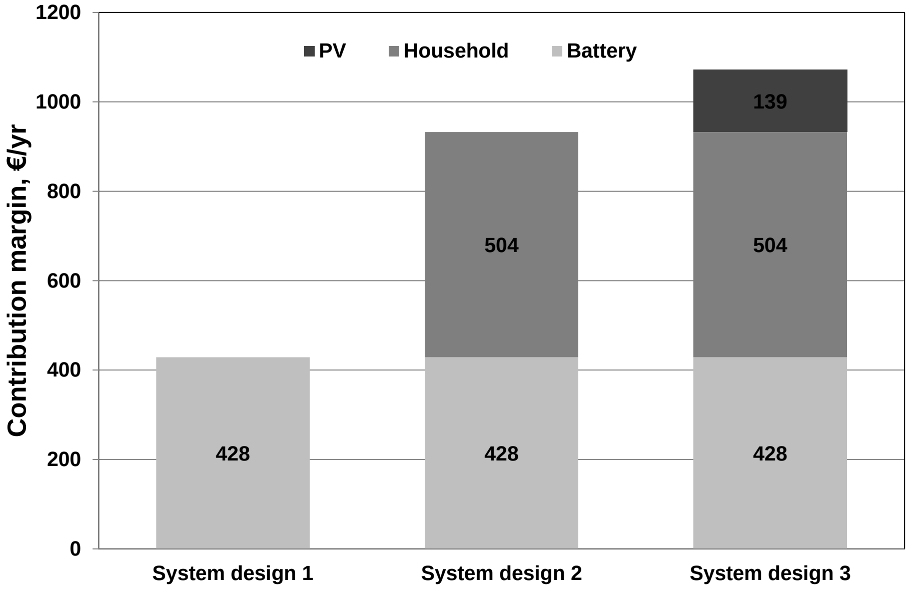

Figure 5: Contribution margin of described system designs due to participation of storage in tertiary and energy exchange market

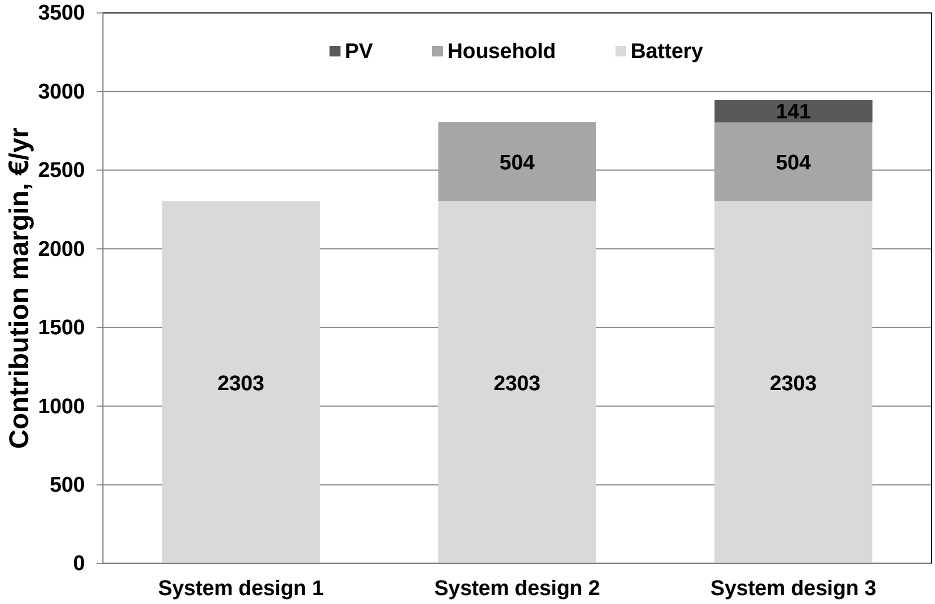

Figure 6: Contribution margin of described system designs due to participation of storage in secondary and energy exchange market

Figure 6 depicts the corresponding results for secondary control market. The contribution margin of secondary market (2,303 €/yr) is much higher than tertiary control market (428 €/yr). The main reason lies in the low number of called tertiary control energy in APG control area.

Figure 7 shows the impact of energy and power price variations in conjunction with EES at the secondary control market. The variation of energy prices (negative or positive secondary control) has a higher impact of contribution margin compared to power price variations.

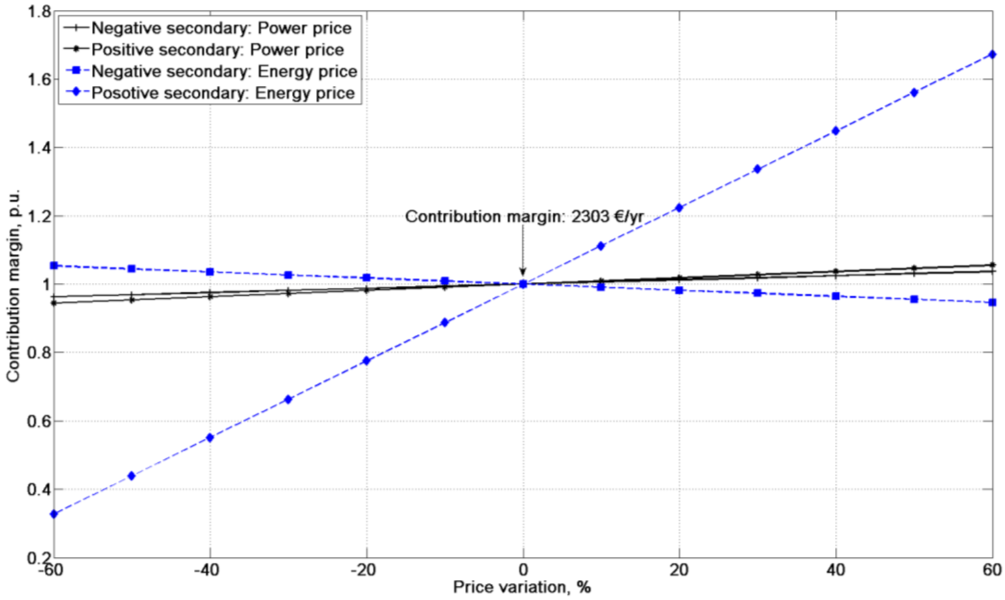

Figure 7: Sensitivity analysis of VRB participating in energy exchange and secondary control market

5 Conclusion

The investment cost including inverter, installation and reinvestment for analysed VRB (100 kWh, 10 kW) is about 19,433 €/kW [10]. The yearly cost consists of annuity (interest rate = 7 %, life time = 20 years with mentioned capacity limits) and running cost (3500 €/yr), is about 18,344 €/yr. The contribution margin from EES participating in secondary control market and energy exchange market reduces the yearly costs to 16,041. It means for achieving of the break-even point, the yearly costs must be cut down by about 87.44 %. The realisation of the mentioned cost reduction currently might hardly be reached neither due to economies of scale of analysed EES system/ related technologies nor by the expectation of significantly higher contribution margins at the control markets. Thus a deployment of VRB batteries at control energy market cannot be recommended at current battery cost and revenue conditions. As a consequence, other business models such as the usage of VRB batteries as backup power in areas with high grid outage rates are more likely to perform economically.

Acknowledgment

We would like to acknowledge the financial support by the Klima and Energiefonds in terms of the research programme “Neue Energien 2020” for the project “Multifunktionaler Batteriespeicher” as this project is vital for the content of this paper.

Appendix: List of Symbols

$Control_{power,negative}$	Power revenues due to providing of negative power control
$Control_{power,positive}$	Power revenues due to providing of positive power control
$Control_{energy,positive}$	Energy revenues due to providing of positive power control
$Exchage_{Market,energy\ sell}$	Energy revenues due to participation on energy exchange market
$Exchage_{Market,energy\ purchase}$	Energy expenses due to participation on energy exchange market
$P_{Charge,t}$	Charging power at time t
$P_{Discharge,t}$	Discharging power at time t
$S_{VRB,Control\ market,Positive}$	EES status at the beginning of a positive control block
$S_{VRB,Control\ market,Negative}$	EES status at the beginning of a negative control block
$S_{VRB}(t)$	EES status at the specific time t
t	An hour within a year

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