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Analyis of a Potential Single and Combined Business Model for Stationary Battery Storage Systems

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Abstract

With regard to a successive penetration of renewable energies and the implied need for system flexibility, stationary battery storage systems (BSS) are seen as hybrids, which can manoeuvre either on the demand or on the supply side, due to the bidirectional transformation process. In the scientific debate, the revenue side for BSS are often just titled and partially mapped for individual markets, which frequently leads to the conclusion that the investment in BSS does not pay off. Therefore, the core concept of the paper is the strategy to combine applications and their values, in order to extend the financial attractiveness. To specify and exemplify monetary value propositions (applications) and value networks (benefits) as well as the combination theory, a single and combined revenue model is examined: energy trading via day-ahead market (arbitrage) and energy trading in combination with frequency support via secondary control. The results show, that depending on the technology, the combined revenue model reduces the load factor and thus theoretically expands the BSS lifespan. Moreover, with modified market rules and individual bidder strategies there is a potential to generate higher proceeds with the combined revenue model.

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Keywords: Battery storage systems, Optimization, Business model, Arbitrage, Day-ahead market, Frequency support, Secondary control reserve

1. Introduction

In the future German power system, characterized by high penetration of intermittent renewable energy sources (RES), the demand and the importance for flexibility options will rise. However, in this setting the main flexibility

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shares can be covered with other more cost effective measures than stationary battery storage systems (BSS), but there is still a projected, quantity-wise uncertain market-based demand for electrical storages – especially, when intermittent RES become the pre-dominant generation technique [1], [2], [3]. Consequently, a market and technology progress as well as commercialization of appropriate battery storage options is obligatory for the future electricity system in Germany. Therefore, the scientific debate about BSS is progressively intensive concerning technical, legal, and economic issues. Currently, the economic analyses are mainly focusing on the cost side [4], [5], [6], the revenue side is often just titled and only partially mapped for individual applications, which frequently leads to the conclusion that single application areas often do not achieve the necessary margins to operate economically. However, due to bidirectional transformation process, batteries are multi-application technologies: They are applicable in many different ways by diverse shareholders and thus, have different potential value creation sources [7]. In broad terms, there are two forms how to gain monetary benefits along the electricity value chain with existing BSS applications in the German electricity market: First, revenues received by the storage owner or operator and second, cost reduction or avoidance by the storage owner or operator [8]. Generally, revenues can be realized over existing markets and bilateral contracts. Whereas cost reduction or avoidance is highly based on individual use cases. Figure 1 illustrates estimations of value potentials along the electricity value chain for the German power segment of 2013.

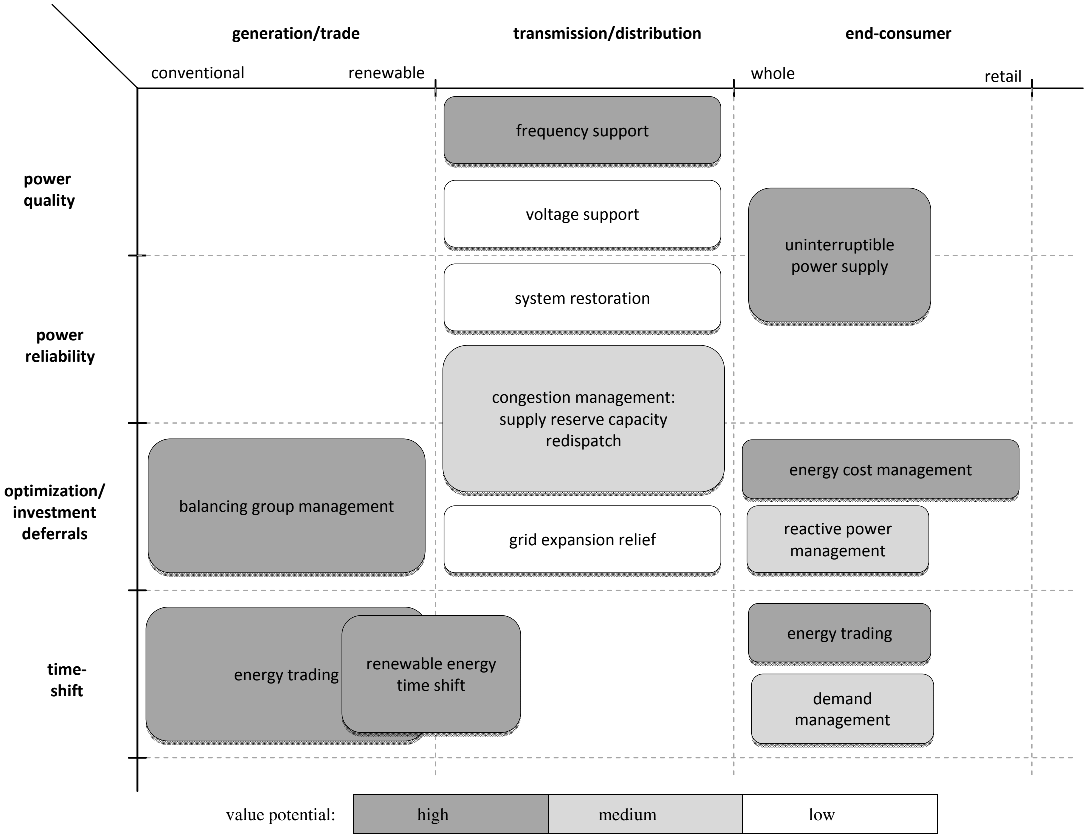

Fig. 1. BSS value propositions (applications) and value networks (benefits) along the electricity value chain.

According to the results of the benefit analysis, battery applications with a high value potential (with regard to benefit potential, good applicability, and favorable legal environment) are: energy trading at the day-ahead and intraday market, frequency support (especially primary and secondary control reserve), uninterruptible power supply, balancing group management, energy cost management and renewable energy time shift. Applications with a medium value potential are: redispatch, demand management and reactive power management. A low value potential for BSS have: grid expansion relief, voltage support and system restoration.

In addition to economic parameters, individual benefit cases and their combination potential are largely determined by technical and regulative parameters in distinctive market settings [9]. Considering the respective technical and regulative parameters for the German market, figure 2 illustrates combination potentials. In general, a possible combination exists, when there is no capacity expansion. However, the use of energy can be subject of opportunity considerations. The combination estimates are partially dependent upon various conditions, which are indicated in form of numbers in figure 2.

+ yes | **~ possible** | **- no**

business fields	**day-ahead market**	intraday market	primary control reserve	**secondary control reserve**	tertiary control reserve	voltage support y	system restoration x	redispatch	uninterruptible power supply x	balancing group management management	energy cost management	reactive power management y	demand management	renewable energy time shift
day-ahead market	■	~3	-	~1	~1	~	-	-	-	-	-	~	-	~2
intraday market	~3	■	-	~1	~1	~	-	-	-	-	-	~	-	~2
primary control reserve	-	-	■	-	-	~	-	-	-	-	-	~	-	-
secondary control reserve	~1	~1	-	■	-	~	-	-	-	~4	~5	~	~1	~6
tertiary control reserve	~1	~1	-	-	■	~	-	-	-	~4	~5	~	~1	~6
voltage support y	~	~	~	~	~	■	-	~	-	~	~	-	~	~
system restoration x	-	-	-	-	-	-	■	-	-	-	-	-	-	-
redispatch	-	-	-	-	-	~	-	■	-	~7	~7	~	~7	~7
uninterruptible power supply x	-	-	-	-	-	-	-	-	■	-	-	-	-	-
balancing group management	-	-	-	~4	~4	~	-	~7	-	■	~	~	~8	~8
energy cost management	-	-	-	~5	~5	~	-	~7	-	~	■	~	~	~8
reactive power management y	~	~	~	~	~	-	-	~	-	~	~	■	~	~
demand management	-	-	-	~1	~1	~	-	~7	-	~8	~	~	■	~8
renewable energy time shift	~2	~2	-	~6	~6	~	-	~7	-	~8	~8	~	~8	■

regarded combination | high value potential

X. No simultaneous battery storage usage, only possible through capacity expansion. Interesting for applications where full discharge reduces the lifespan.
Y. Only possible if the inverter is correspondingly larger.
1. Depending on the storage operating strategy.
2. Depending on the market price, the energy can be used or sold.
3. If the battery on the day-ahead market for intertemporal arbitrage transactions cannot be used, additional use on the intraday market is theoretically possible.
4. If there is no demand for control energy, the storage can be used for balancing group management.
5. Depends on the operation strategy of the energy cost management.
6. Depends on the operation strategy of the RE time shift.
7. If the battery storage after the query of the network operator is in a corresponding operation state.
8. Opportunity consideration; interruption of the current operation mode in favor of the other.

Fig. 2. Value compatibility matrix.

The overall result of the compatibility matrix shows that there are clear exclusion criteria for combinations, however, for combined business cases certain operation conditions must be fulfilled. Especially opportunity considerations underline the necessity for detailed benefit simulations, in order to specify the revenue model and thus the combined value potential. A specific single and combined value simulation is conducted for the combination day-ahead market and secondary control market. This combination is selected, because both BSS application areas operate on existing markets with uniform and standardized product requirements (s. table 1).

Table 1. Main product characteristics DA and SCR [10], [11].

	Secondary Control Reserve (SCR)	Day-Ahead (DA)
tender period	weekly	Daily
tender time	normally Wednesdays (W-1)	everyday 12 noon
product time-slice	peak (HT): Mo-Fri 8 am to 8 pm off-peak (LT): residual period	Mo-Sun every hour
award criteria	power price (pay-as-bid)	unifrom price auction
remuneration	power price and energy price	energy only (marginal cost)
minimum power	± 5 MW (5 MW)/pooling	0.1 MW
capacity	$\geq$ 12h x P_offer	$\geq$ 1h x P_offer

2. Methodology

In order to quantify total revenue potentials for a BSS, the maximum achievable proceeds for a single and combined storage operation mode are simulated: in one operation mode the BSS operates, based on a load-levelling principle, only at the day-ahead market and in another variant, additionally to the day-ahead market, is marketed in the secondary reserve control market.

2.1. The arbitrage model

In table 2 the parameters used to simulate an optimal storage operation mode for the day-ahead market are listed.:

Table 2. Arbitrage model parameters

t	time period (in case of the day-ahead market one hour)
q_{max}^{E}	maximum quantity which can be sold or discharged (German Entladen) in one period [MWh]
q_{max}^{B}	maximum quantity which can be purchased or charged (German Beladen) in one period [MWh]
SOC_{max}	maximum State of Charge [MWh]
η	charging losses or storage efficiency

To maximize the arbitrage yield, an optimization in Matlab is conducted with the mathematical approach of linear programming:

$$\min_{x} f^{T}x \begin{cases} Ax \leq b \\ lb \leq x \leq ub \end{cases} \tag{1}$$

The assessment is carried out with an optimization tool of Matlab, using the integrated solver Linprog.

The state of charge (SOC) of the storage device at time t results from equation (2). The round-trip efficiency losses of the battery are fully attributed to the conversion efficiency when loading the battery.

$$\mathrm{SOC_t} = \mathrm{SOC_{t-1}} + \eta * \mathrm{q_t^B} - \mathrm{q_t^E} \tag{2}$$

With the applicable boundary conditions:

$$0 \leq q_t^E \leq q_{max}^E \tag{3}$$

$$0 \leq q_t^B \leq q_{max}^B \tag{4}$$

$$0 \leq SOC_t \leq SOC_{max} \tag{5}$$

The quantity of energy purchased (loaded) and sold (unloaded) at each time step is described by x and thus is defined as:

$$x = [q_1^E \quad q_2^E \quad \dots \quad q_t^E \quad q_1^B \quad q_2^B \quad \dots \quad q_t^B\ ]^T \tag{6}$$

Therefore, the following three equations of the model result for vector x in the context of equation (2):

$t = 1\ \ SOC_1 = \eta * q_1^B - q_1^E$
$t = 2\ \ SOC_2 = \eta * q_1^B - q_1^E + \eta * q_2^B - q_2^E$
$t = 3\ \ SOC_3 = \eta * q_1^B - q_1^E + \eta * q_2^B - q_2^E + \eta * q_3^B - q_3^E$

Illustrated in a matrix form, this yields to the following equation:

$$\bar{A}x = SOC, with\ \bar{A} = [A_E | A_B] \tag{7}$$

With matrices of dimension $t \times t$:

$$A_E = \begin{bmatrix} -1 & 0 & 0 & \dots & 0 \\ -1 & -1 & 0 & \dots & 0 \\ -1 & -1 & -1 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ -1 & -1 & -1 & \dots & -1 \end{bmatrix} \tag{8}$$

$$A_B = \begin{bmatrix} \eta & 0 & 0 & \dots & 0 \\ \eta & \eta & 0 & \dots & 0 \\ \eta & \eta & \eta & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \eta & \eta & \eta & \dots & \eta \end{bmatrix} \tag{9}$$

$$SOC = [\ SOC_1\ SOC_2\ SOC_3 \dots SOC_t\ ]^T \tag{10}$$

With the applicable boundary conditions of q_t^E and q_t^B, which are defined in the equations (3) and (4), the upper and lower limits of the optimization algorithm Linprog are described.

$$lb = [0 \dots 0]^T; \tag{11}$$

$$ub = [q_{max}^E \dots q_{max}^E\ \ q_{max}^B \dots q_{max}^B\ ]^T \tag{12}$$

The boundary condition for SOC_t from equation (5) is integrated in the optimization as the following:

$$\bar{A}x \geq 0 \tag{13}$$

$$\bar{A}x \leq SOC_{max} \tag{14}$$

$$Ax \leq b \; with \; A = \begin{bmatrix} -\bar{A} \\ \bar{A} \end{bmatrix}; \tag{15}$$

$$b = [0 \ldots 0 \;\; SOC_{max} \ldots SOC_{max}] \tag{16}$$

The maximum revenue $\bar{E}$ results from the product of the amount of energy sold or purchased with the corresponding price. Therefore, the key financial parameters of interest are:

p_{At}	hourly prices at the day-ahead market [€/MWh]
$E_{A,Total}$	total revenues of an arbitrage optimization period [€]

$$\bar{E} = \sum_{t=1}^{t} [p_{At} * q_t^E - p_{At} * q_t^B] \tag{17}$$

$$f = \begin{bmatrix} -p_1 \\ -p_2 \\ \vdots \\ -p_{At} \\ +p_1 \\ +p_2 \\ \vdots \\ +p_{At} \end{bmatrix} \tag{18}$$

Since Linprog only permits minimization optimization - and in this model the purpose is not to minimize costs but to maximize revenues - the formula must be rearranged to $E_{A,Total}$.

$$E_{A,Total} = -f^T x \tag{19}$$

2.2. The arbitrage and secondary control reserve model

For the combined operation mode, the arbitrage model is adjusted according to the market conditions for secondary control reserve. In order to simplify the model, it is assumed that there is no secondary balance demand for the entire provision time. Consequently, only the power provision of each secondary control reserve is regarded. Hence, the following equation for SOC can be defined:

$$SOC_{\mathrm{HT/LT,Start}} = SOC_{\mathrm{HT/LT,End}} \tag{20}$$

$SOC_{\mathrm{HT/LT,Start}}$	secondary control reserve start SOC condition
$SOC_{\mathrm{HT/LT,End}}$	secondary control reserve end SOC condition

The inequality constrain of equation (1) still applies, but the vector b in its function to limit the minimum and maximum charge states must be changed in accordance to the respected control reserve offer (s. table 1).

$$b_{HT,NEG} = [0 \dots 0 \;\; SOC_{max} \dots SOC_{max}] \tag{21}$$

It applies: $b_{HT,NEG}(\mathrm{t}) = 0 \;\; ,\forall \, \mathrm{t} \;\; \in \mathrm{HT}$

$$b_{HT,POS} = [0 \dots 0 \;\; SOC_{max} \dots SOC_{max}] \tag{22}$$

It applies: $b_{HT,POS}(\mathrm{t}) = -SOC_{max}, \forall \, \mathrm{t} \;\; \in \mathrm{HT}$

$$b_{LT,NEG} = [0 \dots 0 \;\; SOC_{max} \dots SOC_{max}] \tag{23}$$

It applies: $b_{LT,NEG}(\mathrm{t}) = 0 \;\; ,\forall \, \mathrm{t} \;\; \in \mathrm{LT}$

$$b_{LT,POS} = [0 \dots 0 \;\; SOC_{max} \dots SOC_{max}] \tag{24}$$

It applies: $b_{LT,POS}(\mathrm{t}) = -SOC_{max}, \forall \, \mathrm{t} \;\; \in \mathrm{LT}$

The total revenue $E_{A+R,Total}$ for the combined markets is the sum of the proceeds for the control reserve $E_{A+R,Regulation}$ and the income from the arbitrage model $E_{A+R,Arbitrage}$.

$$E_{A+R,Total} = E_{A+R,Arbitrage} + E_{A+R,Regulation} \tag{25}$$

The revenues from the control reserve are multiplied by the reproached power rating of the BSS $q_{Regulation}$ and the marginal control reserve power price $p_{t,HT/LT}^{POS/NEG}$. The following applies:

$$E_{A+R,Regulation} = q_{Regulation} * \, p_{t,HT/LT}^{POS/NEG} \tag{26}$$

The power rating of the BSS results out of the following consideration: In principle, according to pre-qualification criteria, each control reserve provider must maintain its power for the entire product time-line. Consequently, the following equation applies.

$$q_{Regulation} = \frac{SOC_{max}}{t_{Regulation}} * \sqrt{\eta} \tag{27}$$

$q_{Regulation}$ marketable secondary control reserve power $\leq \; q_{max}$
$t_{Regulation}$ regulation time period of power provision
$\sqrt{\eta}$ single-trip efficiency

2.3. Model limitations

The arbitrage model for the day-ahead market does not distinguish between conversion and storage efficiency losses. The total efficiency losses of a storage cycle are attributed to the conversion efficiency. In addition, self-discharge losses of the energy storage system due to internal processes are neglected. It is assumed that there are no durable downtimes. By the schedule of a specific BSS operation mode, this should be taken into consideration. Besides, the times for charging and discharging are supposed to be identical, which is not the case for some storage technologies. The reaction time or ramp rate is also neglected in the model, because it is anticipated that for a time horizon of one hour this is of minor relevance. Moreover, the death of discharge is not explicitly addressed in the model and needs to be adjusted for technology specific considerations.

Since the arbitrage model is the fundamental basis for the combined model, the limitations of the arbitrage model persist. Generally, the model extension is grounded on a practice-oriented approach. Meaning, in order to identify the optimal weekly market combination, a day-ahead price forecast for an entire week would be essential, resulting in high model uncertainties due to volatile day-ahead market rates. In addition, for the majority of the currently installed European battery system sizes only a pool marketing at the secondary control reserve market is possible, which implies that trading is feasible only for certain time periods. Therefore, the extended model exclusively simulates specific control reserve time periods and contrasts it to the arbitrage results. Furthermore, for simplification, the combined market model does not regard the frequency and length of potential secondary balance energy demands. However, this restriction would need to be resolved in a specific operator model, because this effects the activity level of a BSS and influences the economic performance.

3. Results

The storage parameters for the model simulation are listed in table 3.

Table 3. BSS model simulation parameters.

Parameter	value	Description
q_{max}^{E}	5 MW	maximum discharge quantity
q_{max}^{B}	5 MW	maximum recharged quantity
$q_{Regulation}$	0.75 MW	marketable secondary control reserve power
SOC_{max}	10 MWh	maximum storage capacity
η	0.8	round-trip efficiency

For both operation modes, it is assumed that the hourly rates at day-ahead market and secondary control reserve power prices are known. Therefore, the simulation is carried out based on ex post data from 2013 of the EPEX-SPOT and the German secondary control reserve market, published on regelleistung.net. The principle function of the two operation modes is described and illustrated by a sample week (September 2-9, 2013) for arbitrage (s. figure 3) and arbitrage in combination with secondary control power provision in the case of HT_POS (s. figure 4).

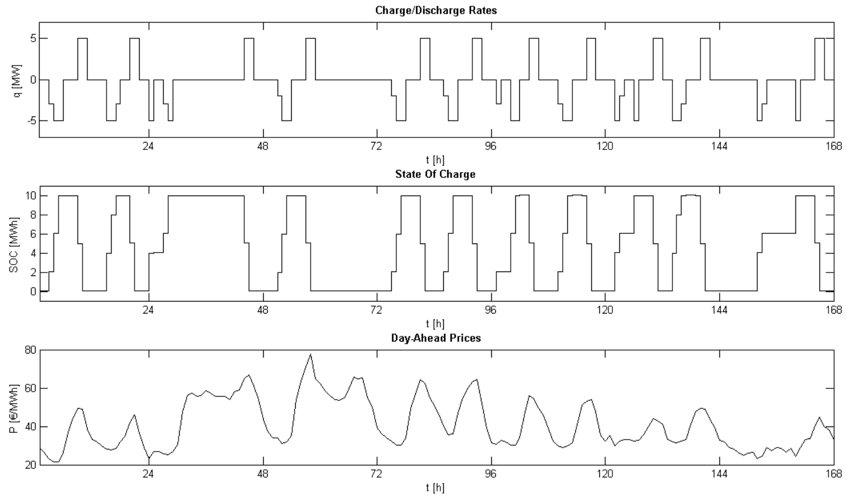

Fig. 3. Sample week DA optimization results, September 2-9, 13.

Principally, in the arbitrage operation mode (DA) the BSS stores electricity in hours of comparatively low market clearing prices and discharges the energy again in times of comparatively high market clearing prices. A positive income can only be generated if the discharge revenues exceed the charge spendings plus the included efficiency losses. Consequently, the state of charge changes in the manner of falling and rising prices at the day-ahead market. Besides, the battery discharges at full power and for these seven days roughly 1.5 charge/discharge cycles per day can be estimated. In 67 % of the 168 hoursthere is no activity at all.

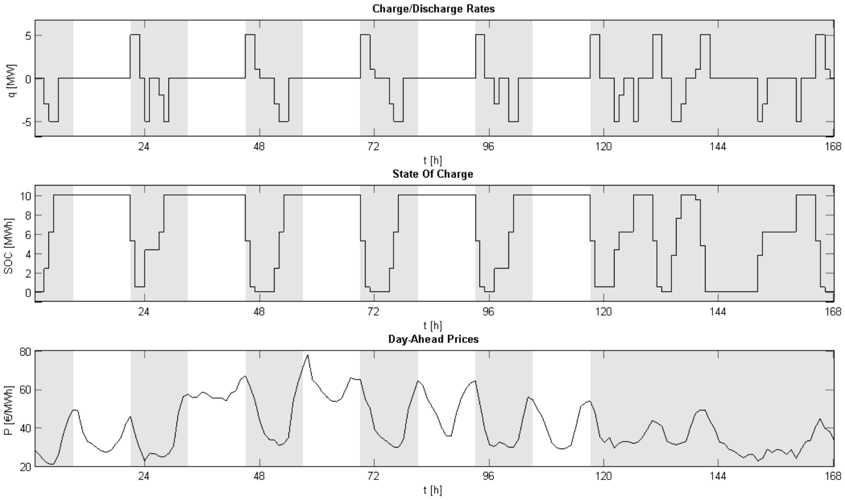

Fig. 4. DA_SCR_HT_POS optimization results, September 2-9, 13.

In the combination of DA_SCR_HT_POS, the BSS is marketed weekdays from 8 am until 8 pm at the secondary control reserve market (s. table I) as positive balance power: The BSS is discharged in the event of a negatively unbalanced control area. Hence, the state of charge of the storage device is at the beginning and for the entire control reserve period SOC_{max} (corresponding, zero for negative control reserve). In order to fulfil this operation mode, the battery has the first eight hours of each simulation period for charging. The example week illustrates that the storage, likewise to the arbitrage model, discharges with its full power and charges just with parts of his power capacity. Furthermore, regardless of any demand for secondary balance energy, the battery completes roughly eight cycles a week. Even during arbitrage periods (for one week HT_POS 108 h), only 40 % of the time is used for load-levelling via day-ahead market price signals.

Due to restricted Central Processing Unit (CPU) capacities, the simulation is carried out on a month-by-month basis, which implies that no energy transfer to the next month is possible. This limits the optimal load path, whereas the impact is assumed to be limited.

Assuming that the storage operator has perfect knowledge of the day-ahead market and behaves as a price taker (quantities are too marginal to be price or/and quantity dominant on the market), the maximum arbitrage revenues for 2013 are 120,120 €, with total operating hours of 2,814, corresponding to a load factor of 32 % per year.

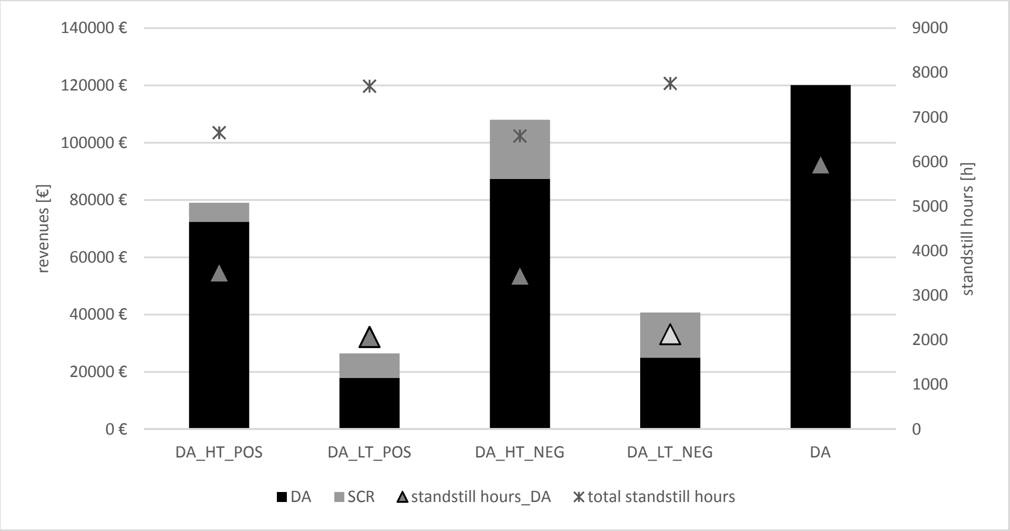

Fig. 5. Revenues and load factor, DA and DA_SCR 2013.

In contrast, the highest proceeds in the secondary control reserve combination can be realized with the combination DA_HT_NEG with 108,011 €, followed by DA_HT_POS with 79,047 €. For both combined benefit fields, the revenues from the day-ahead market are the dominant income factors. The ratio of arbitrage to control reserve is at DA_HT_NEG approximately 4:1 and DA_HT_POS about 11:1. Hence, the storage system generates its main revenues over the day-ahead market. Besides, it is important to note that the load factor for all combined cases ranges between 24 % and 11 % (DA_HT_POS and DA_LT_NEG) and thus is significantly lower than to the single arbitrage case.

4. Discussion

The simulation results show that, only by taking power control reserve remuneration into the total revenue consideration, the proceeds from arbitrage exceed the incomes from all combined revenue options. However, due to the lack of perfect price foreside, in real time trading at the day-ahead market, the proceeds are lower. This persists also for the secondary control market, but generally price estimations in that market are less volatile.

The profit margins for the control reserve revenue depend on different influence parameters. Decisive are the marketable control reserve power according to the pre-qualification criteria (regulative parameter) and additional incomes from control reserve energy demand. The incomes regarding secondary control reserve energy strongly depend on the individual bid strategy of the respective storage operator, whereas the pre-qualification criteria are defined by the regulators. Both have the potential to increase the lucrativeness of the combined revenue model. Assuming an equal return via the secondary reserve control energy price, the proceeds of the combination DA_HT_NEG is 7 % higher than in a single arbitrage marketing. But an active role in the reserve control energy market triggers higher load factors. This central aspect is not part of the model and should be further investigated, because cost or income increases are directly related. In the case of negative control reserve energy demand the storage is charged freely, whereas in the case of positive control reserve energy request the storage is discharged. In terms of an increase to the maximum marketable reserve power of 5 MW, the attractiveness of the combined revenue model escalates immensely. Compared to the revenues exclusively gained on the arbitrage market, the returns in the case of DA_HT_NEG are roughly 90 % higher. Besides, the income ratio from arbitrage to power control reserve deviates and the power control reserve becomes the dominant income factor.

Looking at the standstill hours of the single and combined revenue model, there is still an additional marketable potential. One option to extend the model and the proceeds could be a trading via the intraday market. However, this additional application area causes a higher load factor (more charge and discharge cycles) and thus, potentially lowers the battery lifespan. Besides, it is important to note that trading in the intraday market is more labor intensive (continuous trading) as a trading in the day-ahead (one trade per day) and particularly in the control reserve market (one trade per week).

According to sensitivity analysis, the parameters efficiency and capacity have the greatest influence for both cases in terms of revenue potentials . For the combined option, capacity changes directly affect the marketable reserve control power and depending on the respective underlying capacity prices the changes are equivalent stronger. Regarding the arbitrage model, until a certain capacity increase the storage operator can profit from smaller price spreads. Overall, the round-trip efficiency has the highest impact. At an efficiency level of $\leq$ 78 % the total discrete revenues from DA_HT_NEG are more beneficial than the once form DA. This leads to the conclusion that batteries with lower efficiency levels are better suited for DA_SCR combinations, because the amount of micro-cycles are reduced.

5. Conclusion

Regarding a further successive penetration of RES in the German electricity segment and the implied need for system flexibility, this paper illustrates a comprehensive discussion of today's potential application areas and their value potentials for BSS. The superordinate subject intended, is the concept of combining values in order to extend the financial attractiveness. Based on an optimization model and a case study, a feasible single (arbitrage) and a combined (arbitrage and frequency support via secondary control reserve) revenue model are analysed. The results show that under current market conditions, arbitrage via the day-ahead market is more lucrative then the combination of arbitrage and frequency support in terms of secondary control reserve. However, the profit margins for the control reserve revenue depend on different influence parameters: Crucial are the marketable control reserve power according to the pre-qualification criteria and additional incomes from control reserve energy demand. Regarding the two options, it can be concluded that the highest impact to gain market attractiveness is based on changes in pre-qualification criteria. However, a model differentiation taking power control demands into the simulation is essential for more precise storage operation modes and returns.

Generally, as shown in the value and combination analysis, a variety of other attractive options exists within the German energy market. Therefore, with a progressive market integration of BSS, further single and combined application areas need to be economically specified via explicit model simulations, in order to evaluate different income potentials.

6. References

[1] BMU, "Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global Schlussbericht," Berlin, 2012.
[2] N. Krzikalla, S. Achner, and S. Brühl, "Möglichkeiten zum Ausgleich fluktuierender Einspeisungen aus erneuerbaren Energien," Aachen, 2013.
[3] VDE, "Energiespeicher für die Energiewende," Frankfurt am Main, 2012.
[4] M. Sterner and I. Stadler, *Energiespeicher*. Berlin: Springer, 2014.
[5] H. Kondziella, K. Brod, T. Bruckner, S. Olbert, and F. Mes, "Stromspeicher für die „Energiewende" – eine akteursbasierte Analyse der zusätzlichen Speicherkosten," *Zeitschrift für Energiewirtschaft*, vol. 37, no. 4, pp. 249–260, 2013.
[6] D. U. Sauer, "Marktanreizprogramm für dezentrale Speicher insbesondere für PV - Strom," Aachen, 2013.
[7] B. Battke, "Multi-purpose technologies, lock-in and efficiency – Policy implications from the case of stationary electricity storage," ETH Zürich, 2014.
[8] G. Corey and J. Eyer, "Energy Storage for the Electricity Grid : Benefits and Market Potential Assessment Guide A Study for the DOE Energy Storage Systems Program," New Mexico, 2010.
[9] IRENA, "Battery Storage for Renewables : Market Status and Technology Outlook," Bonn, 2015.
[10] Consentec, "Description of load-frequency control concept and market for control reserves Study commissioned by the German TSOs," Aachen, 2014.
[11] L. Hirth and I. Ziegenhagen, "Balancing Power and Variable Renewable," *Renew. Sustain. Energy Rev.*, 2015.