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The Influence of Frequency Containment Reserve on the Efficiency of a Hybrid Stationary Large-Scale Storage System

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Abstract

Large-scale battery storage systems are predestined for balancing the fluctuating feed-in from renewable energies and supporting the electricity grid due to their high efficiency. As a result, large-scale storage has gained importance in the market for frequency support reserve (FCR). While the first LSS projects had to be planned without operational experience a couple of years ago, new LSS can benefit from the evaluation of measured field data. Especially the real-word efficiencies are key information for electricity procuring costs and arbitrage trading. To contribute filling this information gap, this paper investigates the efficiency of the hybrid LSS, its transformers, its inverters, the individual battery technologies (two types of lead-acid and three types of lithium-ion batteries) and the influence of FCR provision on efficiency. High-resolution field measurements of the hybrid 6MW / 7.5MWh battery storage system "M5BAT" at the FCR market over several years serve as the basis. The data-based efficiency analysis reveals a high round-trip efficiency of 72.8% (with self-consumption: 66.2%) for the LSS in operation. In this context, the lithium-ion batteries have a higher round-trip efficiency of 97.4% than the lead-acid batteries with 85%. Low load on the transformers and the inverters leads to an average power-weighted power efficiency of less than 95%. The results presented can be used to model LSS and its various system components and battery technologies in order to further analyse the participation in chosen energy markets.

Keywords: Hybrid large-scale batter storage system, Lithium and lead-acid batteries, Inverter and transformer, Frequency containment reserve, Power efficiency, Round-trip efficiency

1 Introduction

Large-scale battery storage systems (LSS) LSS have been playing an increasingly important role in the various energy markets for several years. In Germany, 480 MW [1] of LSS have already been prequalified for the frequency containment reserve (FCR) as of 2022, which corresponds to almost 90% of the market's current tender volume of 555 MW [1]. After recent economically difficult years for LSS, FCR prices have risen significantly again, analogous to all other energy markets, and the value of flexibility is becoming steadily higher in perspective with increasingly volatile power generation. Most of the LSS in place today were implemented as pilot projects, and only rudimentary assumptions about LSS efficiencies and ongoing costs could be made in the planning stages [2, 3]. In the meantime, however, years of operational experience can be used to make planning more concrete and to achieve greater investment security. To contribute to this goal, this paper analyses the 4-year operation of a 6 MW LSS from FCR with a focus on real-world efficiencies. In doing so, it evaluates the efficiency characteristics of five different battery technologies, the inverters, and the entire LSS including the control electronics and peripherals such as air conditioning. The findings can be used for dimensioning and designing LSS for the FCR

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or for trading on the spot market. Trading activities are continuously carried out on this within the FCR in order to optimize the state of charge for the provision of FCR. The concrete research questions are:

1. What is the overall efficiency of a LSS in field operation?

2. What are the single component efficiencies for converter, different battery technologies and peripheral systems?

3. How does the FCR operation influence the efficiencies?

2 Literature review

In the last few years, LSS with their high efficiency and fast response capability have progressively replaced conventional power plants in the reserve market. Available studies on the efficiency of the different lithium and lead-acid battery technologies indicate the round-trip efficiency to range between 79 % and 97 % [4, 5]. Studies on stationary LSS in operation are mainly limited to simulations or laboratory experiments [6–13]. Publications and analyses of the efficiency of LSS with real participation in the FCR market are rarely available, see Table 1.

The comparison of LSS presented in Table 1 shows that the scientific contributions in this research area mainly investigate the efficiency of storage systems of single cell chemistry and for a single complete cycle. The open questions regarding the influence of the FCR market participation on the efficiency of hybrid LSS and their components are investigated and answered in this paper using several years of high-resolution field data of the hybrid LSS "M5BAT". For this reason, section 2 explains the basics of the LSS and the methodology of the analysis procedures, in order to analyse and compare the efficiency of the hybrid LSS, the transformers, the inverters and the individual battery technologies in detail in section 4. Section 5 summarises and gives an outlook. It should be noted that this publication is related to other publications on the subject of evaluation of the LSS “M5BAT” [14].

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Table 1: Literature review on LSS with reference to field measurements [14]

Source	FCR	Technology	Hybrid	E (kWh)	Round-trip efficiency		
					Value in %	Period	With auxiliary
Koller *et al.* [15]	Yes	Lithium	No	580	85	Full cycle	Yes
Lo Schiavo *et al.* [16]	Yes	Lithium based	Yes	4640	77-79	Half-year	Yes
	Yes	$NaNiCl_2$		6150	82-86		
	Yes	Lithium based	Yes	3740	77-79		
	Yes	$NaNiCl_2$		4150	82-86		
Swierczynski *et al.* [17]	Yes	LFP	Yes	100		/	/
	Yes	LTO		300		/	/
Dubarry *et al.* [18]	Yes	LTO	No	250	85-87	Full cycle	Yes
Eckert *et al.* [19]	No	LMO	No	500	85	Full cycle	Yes
Karoui *et al.* [20]	No	Lithium	No	1196	91-92	Daily	No
	No	Lithium	No	4308			
	No	NaNiCl2	No	6336	79		
	No	NaNiCl2	No	188			
Thien, Muenderlein *et al.* [14, 21, 22]	Yes	LMO	No	6455	98	Full cycle	No

3 Methodology

This section describes the basic parameters of the LSS and its battery units as well as the formulas for calculating the efficiency of the system components. The basic design and structure of the hybrid LSS M5BAT and the individual battery units can be found in the background paper [14].

3.1 M5BAT

The hybrid large-scale storage M5BAT has been used exclusively in the market for frequency containment reserve (FCR) since mid-2017 and consists of 10 battery units based on five different battery storage technologies (two different lead-acid technologies and three different lithium-ion technologies) specified in Table 2 [21, 22]. The LTO battery is not taken into account in the further data analysis and evaluation because the storage is not fully functional by mid-2021 and therefore no significant data basis is available [14].

Table 2: Technical information on the different battery units and technologies [14, 23]

Battery unit	Technology	Acronym	DC		AC	
			Capacity in Ah[1]	Energy in kWh[1]	Energy in kWh[2]	Power in kW[2]
1	OCSM	Pb1	1776	1066	1030	617
2	OCSM	Pb2	1776	1066	1030	617
3	OPzV	Pb3	1368	843	814	617
4	OPzV	Pb4	1209	740	715	512
5	LMO/NMC	LMO1	1088	774	748	617
6	LMO/NMC	LMO2	1088	774	748	617
7	LMO/NMC	LMO3	1088	774	748	617
8	LMO/NMC	LMO4	1088	774	748	617
9	LFP	LFP	933	738	713	617
10	LTO	LTO	320	230	222	617

1: Specified for a C-rate of 1/3
2: Including average transformer and inverter losses

The measurement points of M5BAT are shown in figure 1. The schematic diagram shows that measurements are taken at the grid connection, before and after the individual inverters as well as at the individual batteries and transmitted to the EMS. The transformer has no direct measuring points. The state data of the transformers can therefore only be estimated on the primary side in aggregated form via the measuring point at the grid node and on the secondary side for the individual transformers via the aggregation of the measuring points of the connected converters. The accuracy classes of the measuring devices are only known for the LMO battery units and the grid node from the manufacturer's data sheet and are defined as 0.5 for current and voltage. For partial load operation, the measurement error at the grid node increases up to 1.5 % for current and voltage [23].

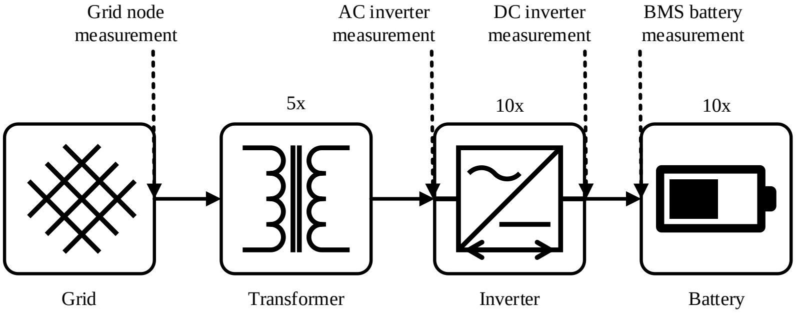

Figure 1: Schematic illustration of the available data measurement points (according to [14, 23])

3.2 Efficiency Analysis

The efficiency provides information about the losses of the system component and varies for the battery depending on the cell chemistry. A distinction is made between power (PE) and round-trip efficiency or energy efficiency (RTE). The measured efficiency for a specific point of time is defined as power efficiency, while the energy efficiency refers to the ratio of input and output power over a period of time. According to the manufacturer, the efficiency of a system component depends on its operation point. In this context, the operation of the system component is assessed by determining the utilisation rate and the power factor.

In this work, the efficiency of the transformers, the inverters as well as the battery units are investigated. It should be noted that the battery units of the large-scale storage do not modify the power compared to the converter and transformer, but instead store it. The assessment of the efficiency of the battery units is therefore limited to the RTE. Furthermore, no direct power measurement values of the transformers are available. For this reason, the aggregated power ratings of the five transformers are evaluated using the measured values at the grid node and at the outputs of the inverters, see Figure 1. The results of the efficiency of the transformers therefore always refer to the group of transformers.

The manufacturers' information on the efficiency of the system components can be found in Table 3. The efficiency ratios are analysed and validated through the efficiency analysis of this work.

Table 3: Power and round-trip efficiency of the system components according to manufacturer's specifications [23]

Battery unit	Batteries		Other
	RTE	C-Rate	PE
Pb1	75	1/10	
Pb2	75	1/10	
Pb3	85	1/10	
Pb4	85	1/10	
LMO1	97	1/3	
LMO2	97	1/3	
LMO3	97	1/3	
LMO4	97	1/3	
LFP	95	1	
Inverter			98.6
Transformer			98

3.2.1 Power efficiency

The evaluation of power efficiency $\mu_{W,t}$ (PE) of a system component for a time t is carried out via the key figures of the PE and is calculated according to Equation 1 and is based on the power P at a time t. Depending on the power flow, the measured power value of the system component is defined as input or output.

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Equation 1: Power efficiency

$$\mu_{W,t} = \frac{P_{Output}[kW]_t}{P_{Input}[kW]_t}$$

The PE varies over time depending on the operating point of the system component. In order to be able to compare the efficiency of different components with each other in this work, the mean power efficiency $\mu_{\overline{W},t}$ (EWPE) of a point in time is weighted with the corresponding power P.

Equation 2: Power-weighted mean of the power efficiency

$$\mu_{\overline{W},t} = \sum\nolimits_t^T \frac{P_{Output}[kW]_t}{P_{Input}[kW]_t} \cdot \frac{P_{Input}[kW]_t}{\sum_t^T P_{Input}[kW]_t}$$

3.2.2 Round-trip Efficiency

The efficiency of the battery units is assessed using the key figures of the energy efficiency or round-trip efficiency $\mu_{Wh,T}$ (RTE) and is calculated according to Equation 3. The key figure $\mu_{Wh,T}$ is based on the energy E of a point in time t. In contrast to the other system components, the measured values of a single measuring point recorded every second are evaluated. For the battery unit, the measured values before the inverter on the DC side are used, for the BESS at the grid node. Depending on the power flow, the measured power value of the system component is defined as input or output

Equation 3: Round-trip Efficiency

$$\mu_{Wh,T} = \frac{\sum_t^T E_{Output}[kWh]_t}{\sum_t^T E_{Input}[kWh]_t}$$

It should be noted that the RTE according to Equation 3 is distorted by a deviation between the initial and final state of charge of the battery over the period T. The influence of the state of charge on the calculation decreases as with increasing number of full cycles. From a number of full cycles of over 100, the distortion is less than 1% and therefore acceptable.

3.3 Statistics

Statistics forms the basis for the empirical collection and analysis of a large amount of data. Applied statistical methods are described in the following.

3.3.1 Weighted Average

The battery units of the M5BAT are characterised by different energy capacities. In order to quantify and compare the battery units as a unit or by battery technology (lithium vs. lead), the mean value is calculated and weighted by the energy capacity of the battery units. The basis for calculating the energy-weighted average can be found in Equation 4.

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Equation 4: Energy weighted average of the battery units

$$\bar{X} = \frac{\sum_{\text{Battery } i} E_i * X_i}{\sum_{\text{Battery } i} E_i}$$

4 Results and discussion

The following section evaluates the performance of the LSS and its individual battery units. The results of this work are based on the adjusted operating data recorded every second from the period between 06/2017 (commissioning of the M5BAT storage system) and 06/2021.

4.1 Efficiency

The efficiency describes the losses of a system component. According to the manufacturer's specifications, the battery and the inverters and transformers have a high efficiency of over 95%. In order to validate the manufacturer's specifications, this section examines the RTE and PE and their influencing factors.

4.1.1 Batteries

The analysis results of the RTE of the battery units are illustrated in Figure 2. The battery units have completed between 127 and 714 equivalent full cycles over 4 years in FCR operation. The RTE of the LSS is therefore specified for at least 100 equivalent full cycles. The reason is that the calculation of the RTE according to Equation 3 is distorted by the deviation between the initial and final state of charge of the LSS over the considered period. The influence of the deviation between initial and final state of charge decreases with increasing number of equivalent full cycles and is less than 1% for a number of more than 100.

The results reveal that all battery technologies have an energy-weighted average RTE of 92.7%. The average RTE changes with the cell technology. Battery units with identical cell chemistry therefore have a RTE of similar proportions. The analysis of the RTE of the different battery chemistries reveals that the lithium batteries have a higher energy-weighted average RTE of 97.4% than the lead batteries with 85%.

This deviation is due to the stronger side reactions of the lead-acid batteries [24]. The calculated RTE of the batteries are in the range of the efficiency evaluations available from other publications excluding secondary losses of the power electronics (transformer and converter). For the lithium batteries, 91% to 98% is given as the range of the RTE [20, 22], for the lead batteries the range is 80% to 90% [25].

In conclusion, lithium batteries with their higher RTE are the most suitable for energy conversion during operation. Lead batteries, with their increased losses compared to lithium batteries, are primarily suitable as reserve storage. A corresponding, efficiency-optimised power distribution in the EMS has the potential to reduce the losses of the M5BAT during operation. A logic of this form is not implemented in the current EMS of the M5BAT and remains an open research question.

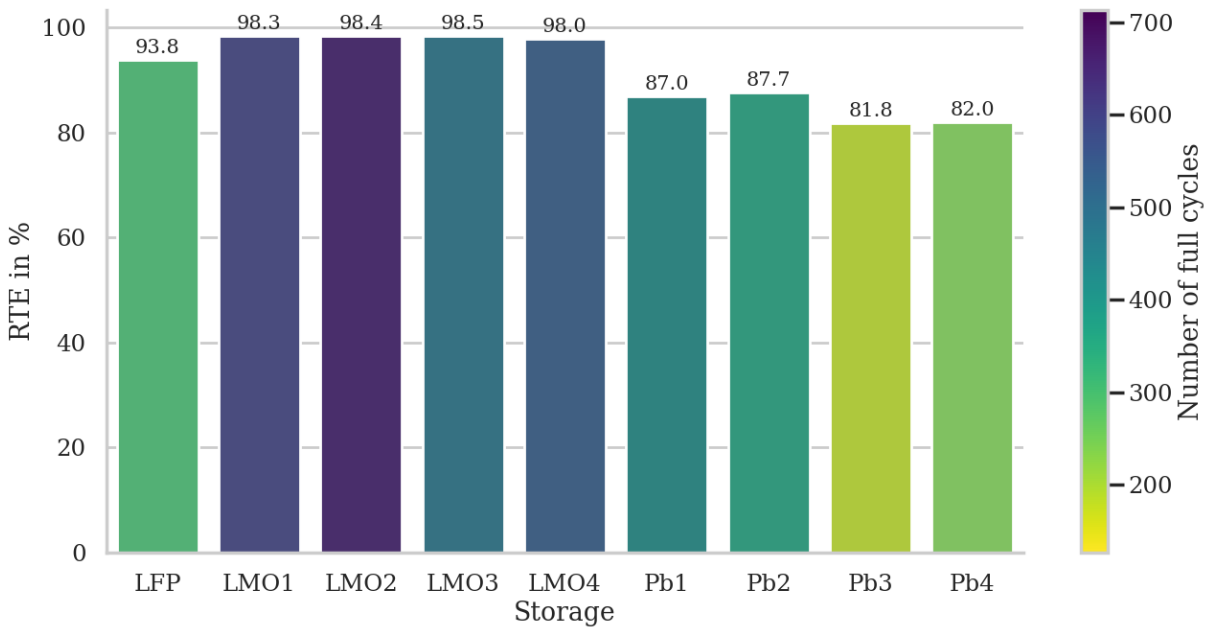

Figure 2: Round-trip efficiency of the battery units as a function of the number of equivalent full cycles

4.1.1.1 Lead-acid batteries

The lead-acid battery units have an energy-weighted average RTE of 85%. Stronger side reactions of the lead-acid batteries compared to lithium batteries negatively influence the efficiency. The RTE of the sealed Pb3-4 lead batteries is 81.9%, which is lower than the 85% specified by the manufacturer. The significant negative deviation of the average RTE of the sealed Pb3 and Pb4 battery units of approximative 81.9% is related to a strong battery degradation of up to 36% [14]. In contrast, the sealed lead batteries Pb1-2 have a higher RTE of at least 87.4% than the manufacturer's specification of the RTE with 75%. The cause of the deviation cannot be derived directly, but could be due to the FCR operation of the battery units.

4.1.1.2 Lithium batteries

The lithium batteries have a higher energy-weighted average RTE of 97.4% than the lead batteries. The LMO battery units have the lowest losses and show an energy-weighted average RTE of approximately 98.3%. The RTE of the LMO battery units is consequently slightly higher than the manufacturer's specification of 97%. The LFP battery unit has a lower efficiency value of 93.8% and falls short of the RTE of the manufacturer's data sheet by 1.2 percentage points. The reason for this could lie in the poor design and configuration of the BMS of the LFP battery unit, which prevents optimal operation of the batteries.

4.1.2 Inverter

The results of the analysis of the PE and the EWPE of the inverters are shown in Figure 3 and Figure 4. In a violinplot the distribution is shown vertically and mirrored around the y-axis. The 50% confidence interval is indicated by a thick black bar in the distribution, the 90% confidence interval by a narrower thin black bar in the distribution. The mean value is marked with a white cross. The statistical evaluation of the efficiency shows that the average PE of the inverters is 75.6%, whereas the average EWPE over all inverters is 94.1%. Negative deviation of the mean PE results from phases of low load and low power factor. As a result, the low PE of the

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individual battery units in Figure 3 have a negligible influence on the mean value of the EWPE in Figure 4 through the weighting with the low power.

The determined EWPE is below the manufacturer's efficiency specifications of 98.6% at nominal power. This is derived from the marketing of the LSS on the FCR market and the resulting deviation from the nominal operation of the inverters with a low average utilisation rate of 15.8%. Publications on the efficiency of the inverter in storage systems confirm that the operation of the inverters at a low utilisation rate is associated with a low power efficiency of less than 60% and thus with high losses [13, 20, 22, 26]. An application-specific design of the inverters and the storage system is for this reason essential for maximising efficiency.

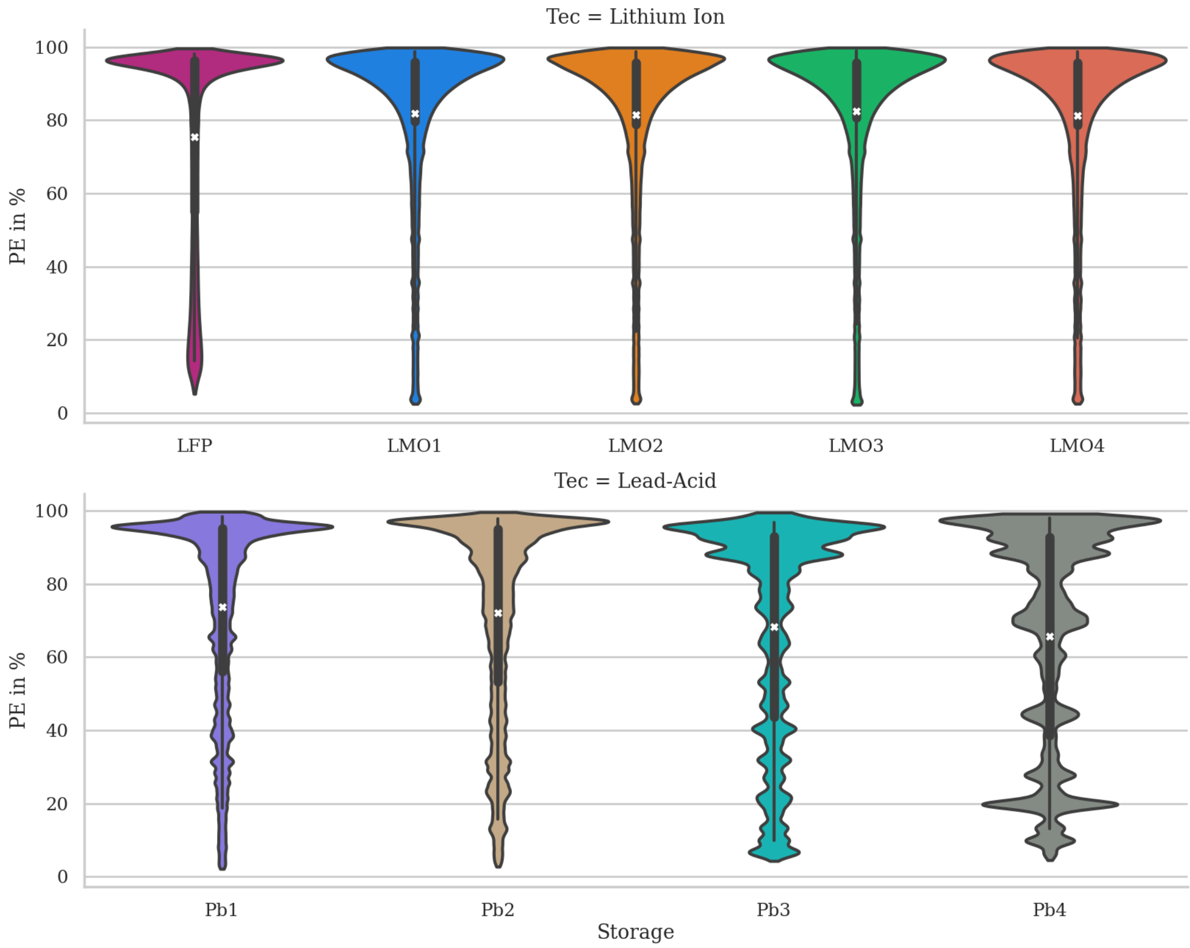

Figure 3: Distribution of the power efficiency for the different inverters

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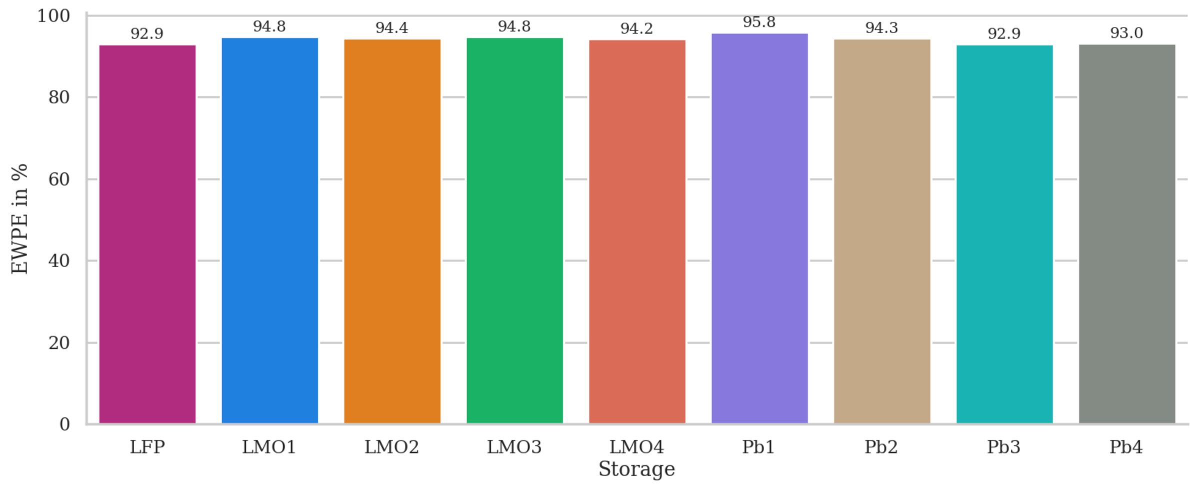

Figure 4: Power-weighted average of the power efficiency of the inverters

4.1.2.1 Lead-acid batteries

The lead-acid batteries have a EWPE of the inverters of approximately 94.2% and a PE of 70.4%. The PE of the inverters is lower for the lead-acid batteries than for the lithium batteries. The reason for this lies in an unstable and weak power prediction of the BMS of the lead-acid batteries. The BMS of lead-acid batteries is not fully developed and can only adapt poorly to age-related changes in the framework parameters of the battery. A significant reduction in power predictions with progressive aging is the consequence and results in an inefficient power allocation by the EMS. This observation is confirmed in Figure 3 by a higher density of PE below 60% for the lead-acid batteries and by the practically negligible influence of the PE on the EWPE due to the power weighting.

4.1.2.2 Lithium batteries

The lithium batteries have a EWPE of the inverters of approximately 94.2% and a PE of 80.6%. The PE of the inverters is higher for the lithium batteries than for the lead-acid batteries. The reason for this lies in a higher participation in the FCR operation through a higher availability as well as in the more stable and higher power forecasts of the BMS of the lithium batteries. More efficient power allocation by the EMS and thus a reduction of losses are the result.

4.1.3 Transformer

The analysis results of the PE of the transformers are shown in Figure 5 in a violinplot. The analysis of the PE in this context is based on the aggregation of the transformers. The background is that the transformers do not have their own measuring points and therefore have to be estimated via the measuring points at the grid node or the converter. The empirical evaluation of the PE indicates that the PE of the aggregated transformers with a mean value of 82.3% and the EWPE of a mean value of 94.6% are lower than the manufacturer's power efficiency claim of 98% at rated power. The reason for this is a low average utilisation rate of 9.75% compared to nominal operation level. This is due to the marketing of the LSS on the primary reserve market and the associated deviating operation of the transformers with a low utilization rate. Publications on the efficiency of the transformer in storage systems confirm that the operation of the transformers at low utilisation is associated with low power efficiencies and thus with high losses [19, 27]. An application-specific design of the transformers and the storage system is consequently essential for maximising the efficiency.

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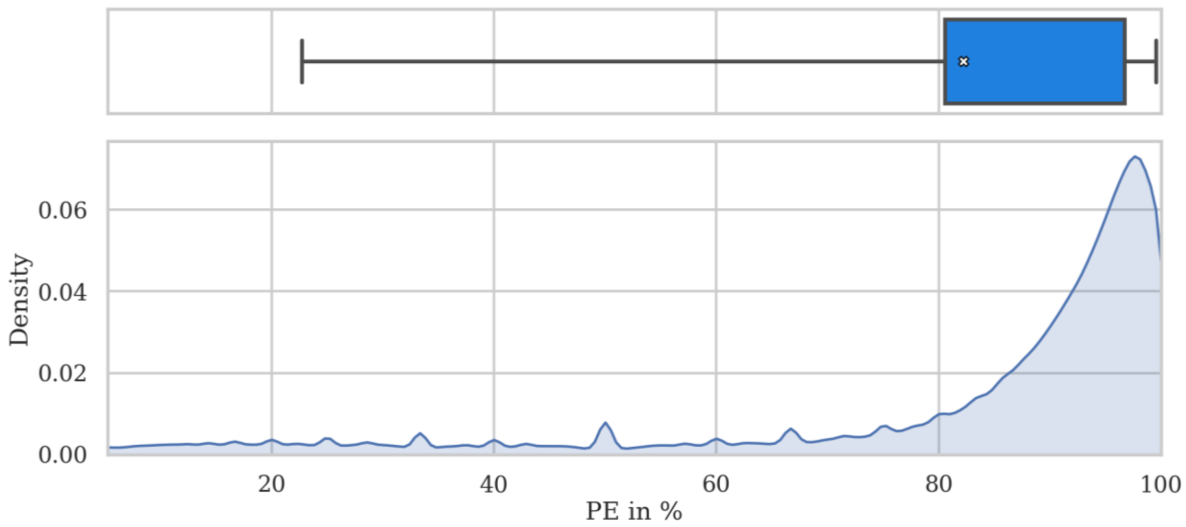

Figure 5: Distribution of the power efficiency of the aggregated transformers

4.1.4 LSS

The results of the analysis of the round-trip efficiency (RTE) of the LSS are illustrated in Figure and Figure 7. The RTE of the M5BAT is shown in Figure for an equivalent of 100 full cycles. The reason for this is that the calculation of the RTE according to Equation 3 is distorted by the deviation between the initial and final state of charge of M5BAT over the observation period. The influence of the deviation between the initial and final state of charge decreases with an increasing number of equivalent full cycles and lies below 1 % for a number of equivalent full cycles higher than 100. For this reason, the time course of the efficiency is given in steps of 100 equivalent full cycles.

The RTE analysis reveals that the RTE of the whole LSS including own consumption is 66.2 % and excluding own consumption is 72.8 %. The RTE of the LSS is composed of the efficiencies of all subcomponents, such as the batteries, the inverters and the transformers, as well as a self-consumption load of 8.58 kW, which results from emergency lighting and cooling and ventilation system, see Figure 7. A comparison of the RTE with results of available publications on the topic of large-scale storage in the field shows that the RTE of LSS is lower. The publications indicate a range of the RTE including secondary losses of the power electronics between 72% and 87% [15, 16, 18, 19, 28]. After examining the efficiency of the batteries, converters and transformers, the low RTE of the LSS can be attributed to the structure and marketing of the LSS on FCR market and the associated low utilisation rate of the power electronics with higher losses. Further losses result from high self-consumption, which is mainly due to the cooling and ventilation system that was oversized in the research project. It should be noted that the weighting of the self-consumption in the calculation of the RTE of the LSS decreases with increasing energy throughput due to the relativisation. The high self-consumption consequently has a higher influence due to the low average load in FCR operation, which will decrease in a multi-use application on top of FCR.

In order to increase efficiency, an optimised, modular design of the storage as well as an optimised operation with higher utilisation of the power electronics via multi-use application on the energy and reserve market is required [13, 28, 29]. In M5Bat, an intelligent EMS for operating the transformers, converters and battery technology at the operating point with the lower losses has the potential to further increase the RTE of the storage. Research on the EMS to reduce losses during operation is already in progress at the institute ISEA.

Furthermore, the deviation of the RTE of M5BAT compared to other publications results from different applications and data bases for the calculation of the RTE. The majority of the publications cited calculate the RTE of the large-scale storage system using an application-independent full cycle Therefore, the storage is discharged and charged one time with a high power and load of the converters and transformers in order to determine the losses afterwards. Consequently, the RTE determined in the publications does not provide any direct information about the efficiency of the battery in everyday life or operation. Some publications calculate the RTE in operation for a longer period of time, from one day [20] to a half-year [16]. However, the Large-scale battery storage systems in the publications referred to are not applied to the primary reserve market and therefore have a different utilisation profile for the batteries and power electronics.

Figure discloses that in the first year of commissioning, the RTE of the LSS is slightly lower than 62%. This is due to the fact that the inverters can only go into silent mode by adjusting the configuration in February 2018, which prevents the power supply to the inverters from being drawn from the battery systems during inactivity. This enables the reduction of losses of the inverters and transformers during inactivity and increases the efficiency. In addition, it can be observed from the results that the LSS approximately completes 100 equivalent full cycles per year and that the RTE determined can accordingly be interpreted as the annual RTE of the LSS.

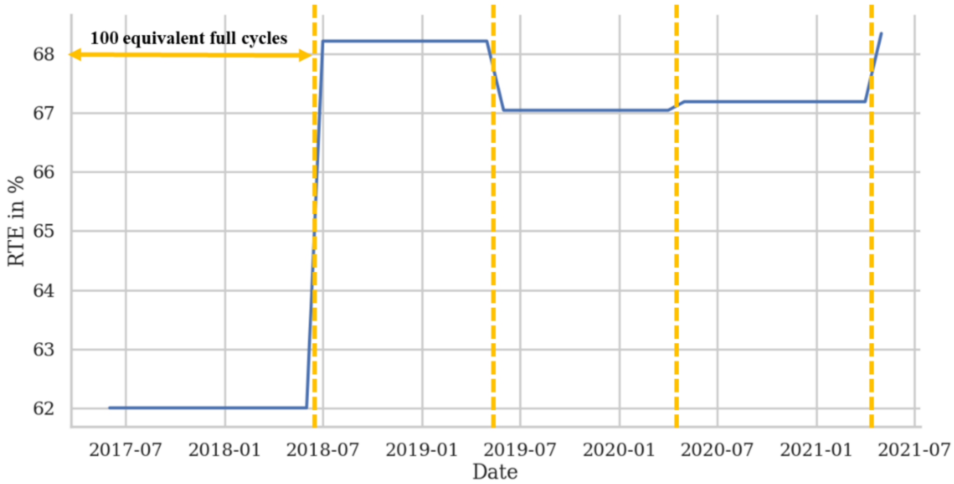

Figure 6: Development of the mean round-trip efficiency of LSS

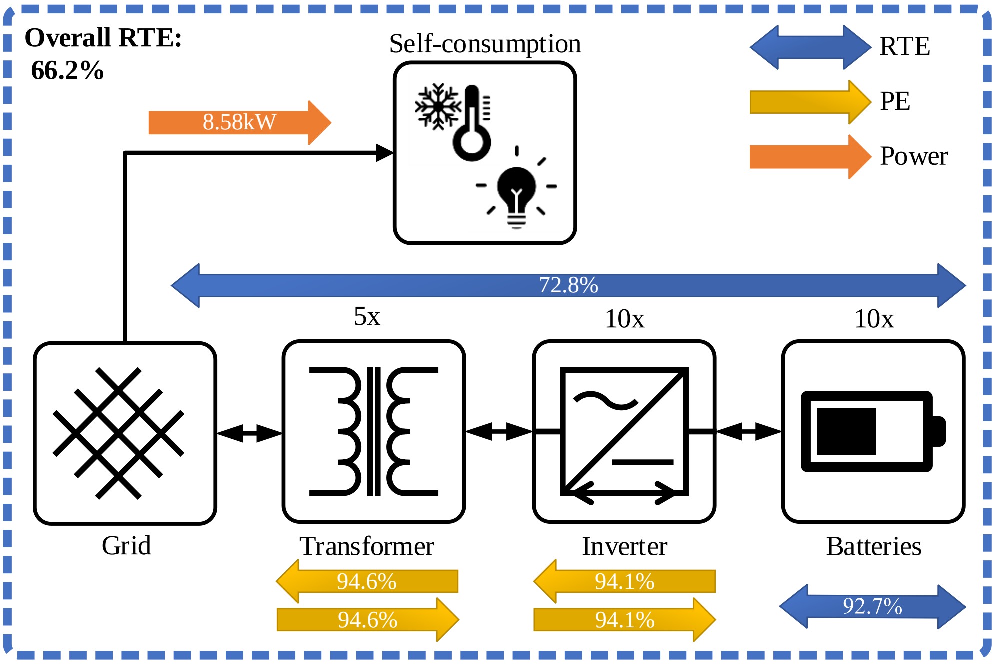

Figure 7: Overview of the efficiencies of the LSS “M5BAT” along the power flow

4.1.5 Costs

With an annual, historical energy throughput of the hybrid LSS “M5BAT” in FCR operation of 1.42 GWh (Charging: 808 MWh, Discharging: 608 MWh) and an average purchase price from the distribution partner on the intraday market of 0.0531 €/kWh, one percentage point loss of the RTE of the batteries results theoretically in additional costs of 563 €/year. In contrast, a reduction of the PE of the inverters or of the transformers by one percentage point leads to additional costs of 752 €/year. This is due to the fact that the necessary energy capacity in the charging and discharging direction for FCR operation is ensured by the process of operating point adjustment on the intraday market. Higher losses consequently have to be compensated during operation via a purchase on the intraday market.

According to the described calculation basis, the use of the more efficient lithium batteries with an RTE of 97.4 % compared to the lead batteries with an RTE of 85 % has a savings potential of 6981 €/a. The converters and transformers with an EWPE of 94.1 % and 94.6 % respectively result in total additional costs of up to 5941 €/year through inefficient operation with low utilisation compared to the power efficiency in nominal operation of 98.6% and 98 % respectively. Intelligent operation of the battery units in the EMS with prioritisation of the lithium batteries for the energy throughput in FCR operation as well as with higher utilisation rate of the power electronics via multi-use application of the LSS on the reserve and energy market has a total savings potential of up to 12922 € per year. It should be noted that the calculated, theoretical cost potential is given for the specific installation and operation of the hybrid LSS “M5BAT” and cannot be considered independently.

5 Conclusion and Outlook

The analysis of the historical data of the hybrid LSS “M5BAT”, operating on the FCR market, has revealed that the LSS has an average RTE of 72.8% (with self-consumption: 66.2%). The battery units, in comparison, have a relatively high average RTE of approximately 92.7%. In this context, the lithium batteries have a higher RTE of 97.4% than the lead-acid batteries with 85%.

The lower round-trip efficiency of the LSS results from the high self-consumption and less efficient operation of the inverters and transformers with an average utilisation of less than 16%. With a EWPE of the inverters of 94.1% and of the transformers of 94.6%, the EWPE of the power electronics is up to four percentage points below the manufacturer's specifications of over 98% at nominal operation. This is due to the low power requirements of the FCR and the structure of the storage. Consequently, a large-scale battery storage system can significantly increase its efficiency through optimised, modular design and control, as well as by combining parallel market applications with FCR.

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Kevin Jacqué: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Data Curation, Visualization, Writing - Original Draft
Lucas Koltermann: Conceptualization, Methodology, Investigation, Validation, Writing - Review & Editing
Jan Figgener: Conceptualization, Validation, Writing - Review & Editing, Supervision
Sebastian Zurmühlen: Conceptualization, Validation, Supervision, Project administration, Funding acquisition
Dirk Uwe Sauer: Conceptualization, Validation, Resources, Writing - Review & Editing, Supervision, Funding acquisition

Conflicts of Interest

The authors do not have any conflicts of interest that could have impacted the content presented in this paper.

Data Availability Statement

The data of the large-scale storage system M5BAT in Aachen is currently not publicly accessible, but will be published in the future after a comprehensive preprocessing and analysis.

Abbreviations/Nomenclature

Abbreviation	Meaning
LSS	Large-scale storage systems
FCR	Frequency containment reserve
PE	Power efficiency
RTE	Round-trip efficiency
EWPE	Power-weighted power efficiency
BMS	Battery management system
EMS	Energy management system
OCSM	Lead-acid batteries with liquid electrolyte
OPzV	Sealed lead-acid batteries with gelled electrolyte
LMO	Li-ion manganese oxide
NMC	Nickel-cobalt-manganese
LFP	Lithium-ion iron phosphate
LTO	Lithium-ion titanate oxide
SOC	State of charge
C-Rate	Charge and discharge rate

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