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APPLICATION POSSIBILITIES AND ECONOMICAL ASPECTS OF ELECTRIC STORAGE DEVICES IN DISTRIBUTION NETWORKS

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ABSTRACT

This paper describes different applications of storage devices to illustrate the spectrum of opportunities in addressing present and future demands of electrical networks. Along with the evaluation of the technical benefit of electric storage systems, the revenue opportunities for different storage applications are presented. Through this, it is illustrated how electrical storage systems obtain their commercial value.

INTRODUCTION

Future energy production will be characterized by an increasing amount of renewable energy sources (RES) feeding into the electricity grid. The increase of distributed generation, especially from small RES and decentralized co-generation plants, is already causing several difficulties in the energy system. Electrical energy storage systems (ESS) provide integrated solutions along the energy value chain in a transforming energy system (see Figure 1).



Figure 1: Storage application in the energy system

Several applications have been evaluated within studies from Siemens AG, identifying storage solutions to technical challenges in future energy networks:

- Peak shaving for industrial loads
- Primary reserve power for frequency control
- Increased utilization of decentralized volatile RES
- Optimization of networks/equipment utilization
- Operation of island-based networks

Besides these technical challenges, storage devices can be used to trade energy from RES for an economical benefit only.

FOCUS: TECHNICAL AND ECONOMICAL ASPECTS OF STORAGE APPLICATIONS

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Electrical storage systems offer a wide spectrum of different applications in electrical networks. The technical aspects and revenue opportunities of the applications described in this paper are illustrated and economically evaluated in the context of the German market and regulatory framework. It must be noted that certain features within this paper are described only to a degree relevant to the evaluated storage application. Therefore, these features sometimes involve more detail than is provided in this paper.

Peak shaving for industrial loads

Current electrical networks are designed to allow the distribution of energy without transmission restrictions or bottlenecks. Therefore, the peak load of the system strongly affects its dimensioning and hence the costs of the electrical network. In Germany, industrial and commercial customers with a consumption of over 100,000 kWh/a pay a price depending on their metered peak load within a certain billing period (month, quarter, year).

The implementation of ESS to "buffer" energy consumption allows a reduction of the peak consumption, thereby flatten the load curve

Delivery of primary reserve power for frequency control

Within the European power system, generators, machines and electrical devices operate at a nominal net frequency of 50Hz. Due to permanent feed-in and withdrawal of electricity, the actual net frequency varies in a narrow range around this target value. In case of significant deviations from the nominal net frequency, transmission system operators (TSO) within the European network ENTSO-E provide reserve control power to compensate.

Depending on the activation time and type, reserve control energy is separated into positive (feed-in) and negative (withdrawal) control energy as well as primary, secondary and tertiary reserve energy, which substitute each other sequentially. Primary reserve power must be activated automatically, come into effect within 30 seconds and must have the capacity for up to 15 minutes of run-time. In Germany, primary reserve control is traded weekly via

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auctioning at *www.regelleistung.net*. With a minimum tender size of 1 MW, primary reserve control must be offered as both positive and negative control energy in one tender. While secondary and tertiary reserve energy is also charged by the actual provided energy, only the provision of capacity is charged in the case of primary reserve energy.

Electrical storage devices can provide primary reserve power, charging the storage in times of an exceeding net frequency (negative reserve energy) and delivering positive reserve energy by discharging.

Increased utilization of decentralized volatile RES

Most RES are characterized by their fluctuating and decentralized occurrence. In contrast to the conventional energy supply, where electricity is produced kilometres away from the demand and is levelled to meet it, wind and solar power plants generate electrical energy with no regard for local demand curves or the dimension of the electrical grid they are directly connected to. Besides the technical challenges this development causes, there are economical aspects to be considered as well. For consumers in situations where electricity production is located at or near to the demand, for example owners of solar panels on the roofs of their buildings, it is reasonable that they consume the locally produced electricity instead of covering their load from the grid only. In Germany, decreasing investment costs led to grid parity of photovoltaic power plants (PV) in 2011, when the levelized cost of energy from recently installed PV systems reached the level of electricity prices for private households [1].

Because generation from RES has the described fluctuating character and demand curves tend to lack temporal flexibility, electrical energy storages offer the possibility to store energy from (surplus) RES and discharge the energy to cover the load in times of RES shortages. This storage operation maximizes the consumption of decentred generated electricity and therefore optimizes the contribution margin of local energy system.

Optimization of networks/equipment utilization

The existing energy network in Germany was designed to meet the needs of a centralized electricity generation and a mono-directional energy flow from source to sink. But especially with the enormous growth of PV connected at lower voltage levels, the technical limits of the distribution system are being met. Further effects of the rising decentralized generation from RES are reverse power flows and several voltage violations in distribution networks. Challenges arising thereof can be approached by alternative operation strategies using controllable PV systems or network devices [2]. Within this study, the application of electrical storage systems within the distribution network was simulated to evaluate the possible impact on challenges like voltage drop and overload of power lines.

Island operation of networks

Industrial networks with unreliable grid connection or networks on small islands are often powered by diesel fuelled generators, or at least use them as a backup power source. These diesel generators have to follow the load and therefore rarely operate at their optimal working point.

The combination of electrical storage and diesel generators enables a more efficient operation of the installed diesel generator and can lead to a reduction in the required diesel capacity. Depending on the charge and discharge efficiency of the storage system, its application allows savings in fuel costs as well as greenhouse gas emissions.

The complete substitution of the installed diesel capacity within industrial or island network with ESS would require specific studies concerning critical factors like load profiles, installed RES, energy infeed by RES, based on past profiles and prognoses, etc.

Energy trading

Electrical energy can be traded on several markets. Besides the market for reserve control energy described above, electricity can be traded via bilateral contracts and on futureor spot-markets. Spot market prices at the European Power Exchange (EPEX) are set via merit order and show a wide range within the last few years. Evaluations of the EPEX spot market show the influence of RES to the market price. Figure 2 shows the hourly price in ϵ /MWh versus the share of RES in the ENTSO-E load in Germany for 2011 and Q1 to Q3 of 2012 [3].



Figure 2: EPEX spot versus Share of RES in Germany

It is notable that market prices decreased in parallel with an increasing share of RES in the energy supply. Due to low production costs and contemporaneity of RES, market prices fall in times of a high share of RES. The so called merit-order-effect [4] leads to the idea of combining RES with electrical storage devices. By uncoupling energy generation and energy sale, a power plant operator of a RES is able to react on price developments and avoid selling the produced energy at times of low price.

RESULTS

As described above, several technical demands can be addressed by electrical storage devices. To evaluate their economical value and revenue opportunity, every application was simulated independently. Typical generation and consumption loads, as well as actual market prices, were drawn into a simulation in Microsoft VBA. Besides that, the dimension of the storage system was chosen to meet the requirements of all analyzed applications and should therefore be considered again, if only one use case is tackled. Within the described evaluation, therefore technical parameters of the analysed storage systems are based on Li-Ion technology and frequency converter technology as experiences with the storage system SIESTORAGE from Siemens are drawn into the described analysis. Table 1 shows the technical data of the simulated storage systems.

Table 1: Technical data of simulated s	storage system
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Parameter	Value
P _{Max in/out}	1 MVA
Capacity	1 MWh
Efficiency _{charge}	92%
Efficiency _{discharge}	92%
DoD _{of usable capacity}	100%

As the described evaluation analyzes the revenue side only, technical parameters like unit life-time cycles have not been considered.

Peak shaving for industrial loads

To evaluate the revenue opportunities of peak shaving, a network with an industrial peak load of 20.81 MW within one year was analyzed. Figure 3 shows the simulated storage operation.



Figure 3: Industrial peak shaving

The green curve illustrates the effect of peak shaving as it shows the load curve measured at the point of withdrawal from the network compared to the initial load (black curve). The former peak load of 20.81 MW could be decreased to 20 MW by discharging the storage system to a minimum state of charge (SoC) of 7 percent. In consequence the peak load could be decreased by 0.81 MW, which results in a reduction of the network costs of approximately 4 percent for the regarding billing period.

Additional benefit: The storage can be used as backup system to avoid impacts of critical fluctuations or errors within the connected network or for a short period as an emergency power supply.

Delivery of primary reserve power for frequency control

Taking the average of the highest and the lowest served bid as well as the average price from the weekly auctioning at *www.regelleistung.net* in 2012 into account, the provision of 1MW of primary reserve power can generate an annual income in the range between 130,000 and 180,000 \in .

Additional benefit: Due to fast controlling systems, Li-ion storage devices can exceed technical requirements and offer even superior balancing services. They can be adjusted to the specific demands of the network they are connected to.

Increased utilization of decentralized volatile RES

To analyze the economic value of the maximisation of local consumption through the described price advantage, a standardized electrical load profile for households was scaled to a peak load of 2 MW. Furthermore the load curve of PV power plants in Germany in 2010 was normalized to an installed capacity from 1 to 10 MW. As the evaluation's focus of this application is on maximisation only, the economic value of the electrical storage arises from times of surplus PV energy. Therefore, the application becomes more attractive the larger the differences between generation and consumption are (see Figure 4).



Figure 4: Annual savings due to the maximization of the local consumption via storage (demand: 2 MW_{peak})

As shown in the figure above additional savings from the storage application are minimal if peak loads of consumption and installed capacity of the PV power plant are in a similar range. However, savings become more and more significant with increasing installed PV capacity and therewith surplus PV energy as well as increasing electricity prices. Annual savings opportunities through a cost reduction in covering the load for different PV capacities and retail prices were simulated and lead to annual savings up to 12.5 percent. *Additional benefit*: EES enable the operator to react on flexible electricity prices as well. Consumption might be

flexible electricity prices as well. Consumption might be shifted to times of lower retail prices to generate an additional benefit.

Optimization of networks/equipment utilization

Network analyses show, that voltage violations and overloads of power lines can be avoided if the excess electricity is stored. Instead of expanding the distribution network, existing power lines and components are able to run within their optimal operation parameters and do not have to be replaced. Unfortunately, detailed evaluation of the economic value of this storage application is not feasible, as the operation and dimension of the storage system both strongly depend on the context and parameters of the connected network and the avoided expansion costs depend on the specifications and components of the associated network.

Additional benefit: The expansion of network segments is not always possible. If power lines are (economically) inaccessible, overstrained power lines can be unloaded by the connection of electrical storage.

Operation of island-based networks

Simulations of island networks indicate a significant impact of ESS to diesel power operation. Comparing the energy supply of diesel generation alone to diesel generation with a connected storage system, analyses show a notable increase in the efficiency of the diesel generation and a reduction of diesel fuel requirements and CO_2 emissions in parallel.

Figure 5 shows the exemplary energy demand of an island through the combination of commercial and private load curves (black load curve).



Figure 5: Storage operation in island networks

Simulating the integration of the described storage device led to an optimized diesel operation (grey area) as the diesel generator can operate longer at a working point with higher efficiency instead of following the load curve. Hence losses due to the efficiency of the storage system evaluations show annual fuel and CO_2 savings of approximately 2 percent and the diesel efficiency could be increased by 0.75 percentage points.

The improvement of this efficiency is even more significant if fluctuating energy sources feed into the network, resulting in ongoing adjustment of the controllable generation. As diesel generators must be dimensioned to the peak load, they mostly run at inefficient working points to cover the residual load. Figure 6 illustrates the storage operation in island networks with a large proportion of RES.



The load curve (black curve) is mainly covered by RES (green area) and diesel generation (grey area), while the storage system is mainly charged in times of surplus RES energy and discharged to level and optimize the diesel generation. Simulation results show an essential increase of the diesel efficiency of approximately 10 percentage points and fuel savings up to 35 percent due to the optimized operation of the diesel generator.

Additional benefit: If an existing diesel generator is to be replaced or retrofitted, the installation of a storage system can reduce the required diesel capacity significantly and enable a more efficient supply of the island network

Energy trading

To weight the economical value of EES for energy trading, the average prices of the hourly EPEX spot market prices of 2012 are analyzed. Using hourly price spreads at the spot market, storage applications may run several cycles per day and can be applied to sell electricity from RES at times of higher prices. Figure 7 shows an exemplary storage operation running two cycles in 24 hours to use market price spreads and uncouple PV generation (yellow curve) from energy selling (blue area).



Figure 7: Trading of PV energy at spot market

The storage operator buys electricity at low prices during night times (black area) and sells it at the first price peak in addition to the generated PV energy. To avoid or minimize the sale of PV energy at low prices (e.g. at noontime due to the mentioned merit-order effect) the operator then stores the produced PV energy and sells that energy at a second price peak in the evening, when electricity generation from PV power plants decreases naturally.

Evaluations show that this operation leads to an additional benefit of approximately 5 percent per year. This benefit increases with increasing spread between times of high and low prices and becomes even more attractive when the storage capacity is used to buy energy at negative prices.

Additional benefit: Spot market prices show essential peaks in situations of a low proportion of RES or even negative prices in situations of a high proportion, as well as significant prices spreads within hours. Analyzing the development of the price spreads between one hour and the following one, another effect of the increasing amount of RES capacity can be indicated. Taking advantage of shortterm price spreads is difficult for conventional power plants, as load ramps create additional costs. However, this operation might become more economical with the addition of a storage system, which provides flexibility and can be substituted by various generation methods sequentially.

CONCLUSION

Analyses show, that electrical storage devices can address the technical challenges of present and future power systems and generate economical value for different applications in parallel. Table 2 summarizes the outcome of the economical analysis of an electrical storage system with 1 MVA peak performance and 1 MWh usable capacity (see table 1).

Table 2: Economical value and revenue opportunities of	
analyzed electrical storage application	

Application	Economical value	Annual benefit
Peak shaving for industrial loads	Savings in grid connection costs	4 %
Primary reserve control	Earnings	130,000 to 180,000 €
Increased utilization of RES	Savings in supply costs	12.5 %
Optimization of networks utilization	Avoided expansion costs	Individual case assessment
Operation of island- based networks	Savings in supply costs	35 %
(RES-) Energy trading	Additional earnings	5 %

The evaluated results show that depending on certain technical and economical factors, storage systems can not only realize essential reduction of costs and emissions but deliver additional benefits like increased network liability as well.

If allowed by the regulative framework and technically feasible, different storage applications might be combined to enable integrated solutions and maximize the economic revenue. Still it must be noted, that the outcomes of this study are strongly dependent on the prevalent market prices and conditions, especially the derived economic outcomes. Therefore, the findings can't necessarily be applied to other countries, but rather they might be used to initiate more specific analyses.

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