Why should the automated guided vehicles' batteries be used in the manufacturing plants as an energy storage?

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Abstract. This paper examines to what extent automated guided vehicles' (AGV) batteries can be used as a mobile electrical energy storage to increase energy flexibility and reduce peak loads in manufacturing plants. First, it is indicated, what demand response and peak shaving in manufacturing mean. Then, existing battery applications for peak shaving are presented. Finally, the benefits and potential of using AGVs as energy storage to reduce peak loads in the company are illustrated, after an approximate cost calculation for peak shaving of a company with AGV batteries are performed in a use case scenario considering AGV availability during manufacturing. The results of the approximate cost calculation show that it can be beneficial for companies to use AGV batteries as an energy storage in manufacturing plants to reduce their peak loads.

1 Introduction

The United Nations General Assembly has set 17 sustainability goals to guarantee the long-term sustainability development of the global community. The seventh of the sustainability goals is to increase the share of renewable energy in the global energy mix [1]. At the international climate conference in Paris in 2015 [2], more than 150 countries agreed to set their individual energy and climate protection targets. The key target for renewable energy was to achieve at least a 32% share in the European Union (EU) in 2030 [2]. As a result, the German government has set a target of generating 65% of its power from renewable sources by 2030 [3].

Power generation from renewable sources fluctuates considerably. Therefore, the energy demand should be flexibly adapted to balance the power grid. This process is called Demand-Side Management (DSM) and in particular Demand Response (DR) [4]. According to the DG ENER working paper [5], which describes the future role and challenges of energy storages, energy storage will play an important role for ensuring a higher security of energy supply even with a more volatile supply.

Special tariff models are common for manufacturing companies, which take into account not only the basic, labor and reactive power price but also the power price. This is often a significant cost component of electrical energy for the companies and depends on the highest peak production load. Energy storage systems were used, studied and integrated in manufacturing plants to reduce peak loads and increase savings for the companies by different researchers [6–14].

This paper examines to what extent mobile electrical energy storage devices of the AGV can be used to achieve same goals. First, existing and developed battery applications for the peak shaving are introduced. Then, the definition of the AGVs is described and the existing battery technologies of AGVs are introduced. After an approximate cost calculation for peak shaving of a company with AGV batteries is performed, the results with potentials and benefits of AGV batteries are indicated.

In the conclusion, it is shown, that it can be beneficial for companies to use AGV batteries as an energy storage in manufacturing plants to reduce their peak loads.

2 Demand Response and Peak Shaving

With conventional power plants, changes in electricity consumption were easily matched by controlling power generation [15]. However, due to the increasing share of renewable energies and their inherent volatility, controlling power generation is not a sufficient strategy anymore [16,17]. Commonly, there are five options to increase necessary flexibility in the electricity system: new flexibility on the supply side [18], expansion of the power grid [19], installation of storage capacity [20], conversion between sectors [15] and new flexibility on the demand side [4]. However, since the first four options show some drawbacks, DSM and especially DR are a competitive option gaining more and more interest.

DR is a category of DSM describing measures that influence the level or timing of power consumption in the short-term, triggered by specific signals such as incentive payments [21,22]. Motivated by such signals, participating power consumers autonomously choose to provide flexibility in their power demand [23]. DR is

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also referred to as load control, which includes load connection, load disconnection, and load shift [24].

From a company's point of view, an important motivation for DR is the so called peak shaving [25]. Peak shaving aims at reducing peak loads by shifting them from peak hours to off peak hours. Thereby, companies can reduce their cost resulting from transmission and distribution system charges [26]. However, a significant digitization of today's electricity systems is necessary to fully automate peak shaving [4,26]. An overview of industrial peak shaving applications is given by [6], whereas [7] complements potential revenue streams.

3 Existing Battery Applications for Peak Shaving in Manufacturing

To enable the peak shaving in manufacturing plants, different types of battery usage applications and concepts were developed. Some researchers investigated the peak shaving opportunities with the stationary batteries in the industrial grid.

Lehmann et al. [6] developed a simulation tool to determine the optimal size of the photovoltaic and battery storage systems (BSS) for industrial peak loads. Braeuer et al. [7] assessed the economic potential to install BSS for German small and medium sized companies and analysed which BSS capacity is optimal for the revenue stream peak shaving. Böttinger et al. [8] developed a simulation model for lithium stationary batteries to reduce operating costs and optimize system lifetime in a manufacturing company. Oudalov et al. [9] designed an optimal operating strategy and model for BSS to reduce peak loads in industrial grid. The model finds the optimal capacity and power of the BSS to provide peak load shaving. Telaretti et al. [11] evaluated the BSS with different battery technologies to determine which battery technology is more suitable to reduce peak load and electric bill of the commercial and industrial consumers in Italy. Tiemann et al. [12] analysed the profitability of the different BSS for more than 5,300 company sites with the goal of reducing industrial grid fee. Zafirakis et al. [13] developed a simulation algorithm, which creates different usage strategies for the BSS to realise peak shaving in a Greek industrial facility.

Electric vehicles' (EV) batteries were also used to enable peak shaving in the industrial grid. Hofmann et al. [14] has used EVs from short-distance traveling employees to reduce the peak loads of the industry grid. Raab et al. [10] used EVs (Vehicle to grid system) to reduce the industrial peak loads with a load balancing system, which is developed by the authors of the paper.

AGV batteries were not addressed in the presented papers except [27]. This paper achieves the reducing peak loads of the grid by using AGV batteries in the port. However, the industry grid is not considered.

It is indicated that the developed different battery usage concepts or applications have a focus on reducing peak loads with stationary, EV and AGV batteries. However, the enabling energy flexibility and reducing peak loads in manufacturing plants with AGV batteries has not been the focus of the research yet.

4 Automated Guided Vehicles

In the following chapter, the definition and different battery technologies of AGV are presented.

4.1 Definition

"Automated guided vehicle systems (AGVS) are in-house, floor-supported materials handling systems comprising automatically controlled vehicles whose primary task is materials transport rather than the transport of passengers" [28].

The most important flexibility factors for conveyor technology include the ability to integrate into the existing manufacturing environment, to transport a wide variety of goods, to adapt to fluctuations in productivity and the possibility of adjusting the sequence of handling. Among all automated conveyor systems, AGVS offer the highest level of flexibility. Other advantages of AGVS are minimal infrastructure requirements, the possible usage of existing routes and the option of simple replacement by another vehicle or a conventional forklift truck. As a result of the various possible applications, there are virtually no limitations in the design of the AGVS [28–30].

4.2 Battery Technologies

This section compares the characteristics of different battery technologies. Table 1 presents the features of common battery types that are used in mobile energy storage devices. The stated values do not always correspond accurately, because there are different constellations for most battery types. According to [31,32] they are as follows:

Table 1. Comparison of battery technologies [31,32].

	Lead	Nickel-		Lithium -		
		cadmium	metal hydride	Ion	titanate	iron phos-phate
Cathode material	PbO_2	NiO(OH)	NiO(OH)	$LiCoO_2$	$LiCoO_2$	$LiFePO_4$
Anode material	Pb	Cd	MH	graphite	$Li_4Ti_5O_{12}$	graphite
Electrolyte	H_2SO_4	KOH	KOH	$LiPF_6$	n.a.	n.a.
Nominal voltage	2.0 V	1.2 V	1.2 V	3.6 V	2.3 V	3.3 V
Cut-off voltage	1.7 V	1.0 V	1.0 V	3.0 V	1.8 V	2.0 V
Operating temperature	-20 to 60°C	-40 to 60°C	-20 to 60°C	-20 to 60°C	-30 to 80°C	-20 to 60°C
Energy density	40 Wh/kg	45-60 Wh/kg	80 Wh/kg	120-200 Wh/kg	70-80 Wh/kg	90-110 Wh/kg
C-rate / performance	very high	very high	high	low	very high	very high
Self-discharge per month	~5 %	~ 20 %	~30 %	5 %	2 %	5 %
Cycle life	200-300	1000-1500	300-500	500-1000	8000	2000
Charging voltage	2.3-2.6 V	C/10	C/4	4.2 V	2.8 V	4.0 V
Charging duration	20 h	11 h	5 h	3 h	1.5 h	1.5 h
Charging efficiency	70-80 %	70-90 %		70-96 %		

5 Approximate Cost Calculation

An approximate cost calculation for peak shaving within a company by AGV batteries is performed considering AGV availability in this chapter. First, the use case scenario is described. Then the results of the described use cases are presented. Finally, the benefits and potential of using AGVs as an energy storage to reduce peak loads in the manufacturing company are illustrated.

5.1 Use Case Scenario

In the use case scenario, it is obtained to calculate the electric bill savings ($c_{savings}$) for a small and medium-sized enterprise (SME) from Germany by reducing the peak loads using AGV batteries. Table 2 and Table 3 show the AGV's and charging station's numbers and properties used in this scenario.

Table 2. AGV properties.

AGV Properties	Value	UoM	Name
Cell Chemistry	LiFePo	-	-
Voltage	48	V	V_{AGV}
Capacity	105	Ah	C_{AGV}
Energy	5,040	Wh	E_{AGV}
Number	30	-	n_{AGV}
Usable battery capacity	80	%	$p_{AGV\_cap\_usable}$
Available capacity	25	%	$p_{AGV\_cap\_avail}$
Capacity for manufacturing purpose	55	%	$p_{AGV\_cap\_manufact}$
Deep discharge/no utilization	20	%	$p_{AGV\_cap\_not\_usable}$
Battery cycles	2,000 [31,32]	-	$n_{AGV\_batteryCycles}$
Battery costs per kWh	127.27 [33]	€	$c_{AGV\_batteryCost}$
AGV Working Time	8	h	$t_{AGV\_working}$

Table 3. Charging station properties.

Charging Station Properties	Value	UoM	Name
Voltage	24	V	V_{CS}
Current	100	A	I_{CS}
Number of chargers	5	-	n_{CS}

It is assumed that the charging stations and AGV batteries support bidirectional charging and only one AGV battery can be connected to the charging station at the same time. Moreover, the AGVs are used in one work shift production, which takes eight hours.

Only AGVs with lithium batteries are considered in the use case scenario. According to study [34], the lithium batteries are most suitable for peak shaving applications. Additionally lithium batteries offer a higher capacity respectively a higher number of charge cycles [29] and most effective for peak shaving application compared to other battery technologies [11,12]. AGVs and charging stations investment costs are not included in this scenario, because it is assumed that the AGVs and charging stations are needed and procured for manufacturing purposes. Only the battery degradation of the AGVs' batteries is considered, because the batteries should be additionally discharged during peak loads shaving, which causes aging of the batteries. The degradation of the batteries is calculated as c_{deg} in the equations.

The power curve of SME's industrial grid, which is used in this scenario, is shown in Fig. 1. It can be observed in the Fig. 1 that the peak loads occur only 112 days in the industrial grid of the SME, which is considered as d_{Peak} in equations.

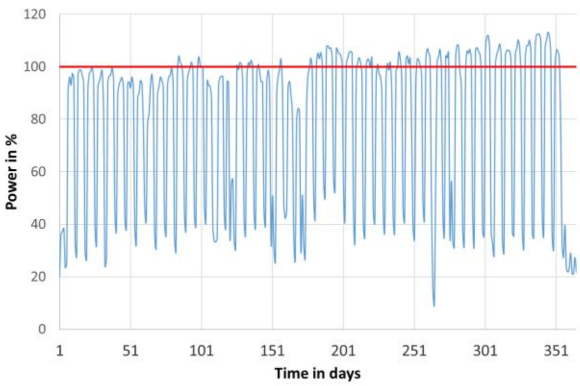

Fig. 1. Power curve of the SME's industrial grid.

Following equations are used to calculate the SME's electric bill savings. In the equations, c_{Elect} means the electricity cost per year (114.78 €/kW/a) for the peak loads of the company. The power, which is used to apply peak shaving in manufacturing plants per year by AGV batteries, is defined as $P_{AGV,PSP,year}$. c_{ch} means the charging costs of the AGV batteries for the SME. In the equation of c_{ch}, $c_{Elect,kWh}$ is used. It is the electricity cost per kWh for the company and is 14 ct/kWh.

$$c_{savings} = P_{AGV,PSP,year} \cdot c_{Elect} - c_{deg} \cdot d_{Peak} - c_{ch} \quad (1)$$

$$P_{AGV,PSP,year} = \frac{E_{AGV} \cdot p_{AGV\_cap\_avail} \cdot n_{AGV} \cdot d_{Peak}}{1000\,\frac{kWh}{Wh} \cdot 24h} \quad (2)$$

$$c_{deg} = \frac{E_{AGV} \cdot c_{AGV\_batteryCost} \cdot d_{Peak} \cdot n_{AGV}}{1.000\,\frac{kWh}{Wh} \cdot n_{AGV,batteryCycles}} \quad (3)$$

$$c_{ch} = \frac{P_{AGV,PSP,year} \cdot 24h \cdot c_{Elect,kWh}}{100\,\frac{ct}{€}} \quad (4)$$

It is verified with the following equations that all AGVs in the scenario can discharge their batteries at the charging stations per day without problem. It is only possible if the power of each AGV battery per hour ($P_{AGV,PSE,hour}$), which is transmitted to the industrial grid during peak loads, should be lower than the power that the charging station can deliver.

$$P_{AGV,PSE,hour} \cdot 1{,}000 \frac{kWh}{Wh} < V_{CS} \cdot I_{CS} \quad (5)$$

$$P_{AGV,PSE,hour} = \frac{E_{AGV} \cdot p_{AGV,cap,avail}}{t_{Disch,allAGVs} \cdot 1{,}000 \frac{kWh}{Wh}} \quad (6)$$

In the equation (7), the discharging times of all AGVs during one day ($t_{Disch,allAGVs}$) are calculated.

$$t_{Disch,allAGVs} = 24h - t_{AGV,\ working} - t_{Ch,\ AGV} \quad (7)$$

The equation (8) shows the required charging time of one AGV per day ($t_{Ch,AGV}$).

$$t_{Ch,\ AGV} = \frac{n_{AGV} \cdot E_{AGV}}{n_{CS} \cdot V_{CS} \cdot I_{CS}} \quad (8)$$

5.2 Results

The AGV batteries can provide in total 176.4 kW power per year for the industrial plant of the SME. It means that the SME can save approximately 18,577 € in this scenario, when the AGV batteries are used as an energy storage with the features (see Table 2 and Table 3) to reduce peak loads of the manufacturing plant.

It is also proved with the help of the equation (5) that the number of the charging stations are sufficient in the scenario so that all AGVs' batteries can be discharged during peak loads at the charging stations.

5.3. Potentials and Benefits

Potentials and emerging benefits of using AGVs in manufacturing plants as energy stores are described in this chapter.

According to the study of Loup Ventures [35], the performance and production of electrically powered AGVs will increase in the next five years. This study also predicts that in 2025 there will be more than 371,000 AGVs worldwide [35]. This high number of AGVs provides a large battery capacity that can be used for energy flexibility measures in the manufacturing companies. Moreover, AGV usage in the manufacturing plants is relevant for 78% of German companies and they are willing to invest in the development of planned energy flexibility measures [36].

According to study [34], the options for optimizing energy procurement, such as grid fee reduction with peak shaving, are gaining in interest for 17 % of companies participating in the survey of the study. 64 % of the companies also emphasized that their employees actively involved in energy storage integration in their company [34]. It shows that energy storage integration is becoming more important for the companies.

Overall benefits for the companies are also described in this chapter. With this concept using AGV batteries as energy storages, companies do not have additional costs for new stationary batteries, battery maintenance and/or charging stations. The batteries are already available in AGVs. Already operating charging stations can be used for peak reducing purposes and power supply for the batteries to enable AGVs to perform its tasks in manufacturing. Employees in companies are already available for AGV maintenance tasks. Additional space problem is defined by the companies as one of the challenges of energy storage integration for stationary batteries [34]. AGV batteries do not require additional space in the company such as stationary batteries. The costs for additional space can be saved.

6. Conclusion

AGV batteries can enable peak shaving and reduce electricity costs for companies. In this paper, demand response and peak shaving definitions are described. Then existing battery applications for peak shaving are illustrated. It is determined that AGV batteries for peak shaving have not yet been used in manufacturing plants.

After the approximate cost calculation with AGV batteries for the SME is performed, it is stated that it can be in some use cases beneficial for the companies to use AGV batteries as an energy storage for reducing peak loads. As seen in the described use case of the approximate cost calculation, the SME could save 18,577 € theoretically, when they would use the AGVs as an energy storage in their manufacturing plant. Therefore, it is recommended to further research in this area and develop a system so that the AGV batteries can be integrated into the company's power system for reducing peak loads.

As a future work, a generic approach concept considering AGV battery charging methods and schemes will be designed and a battery usage algorithm service that enables the AGV batteries to use as an energy storage to reduce peak loads and electric bills for companies, will be developed and evaluated according to the generic approach concept.

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