# Interaction between Charging Management and Battery Ageing

## How a good charging management system can sustainably extend battery life

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The battery system is the "heart" of every electric bus: It not only defines the bus's technical properties, but also significantly influences the costs. A battery system is by far the most expensive component in an electric bus, accounting for up to a third of the acquisition costs. In addition, the lifespan of current solutions is still limited, meaning that transport operators have to plan at least one battery replacement for the service life of an electric bus.

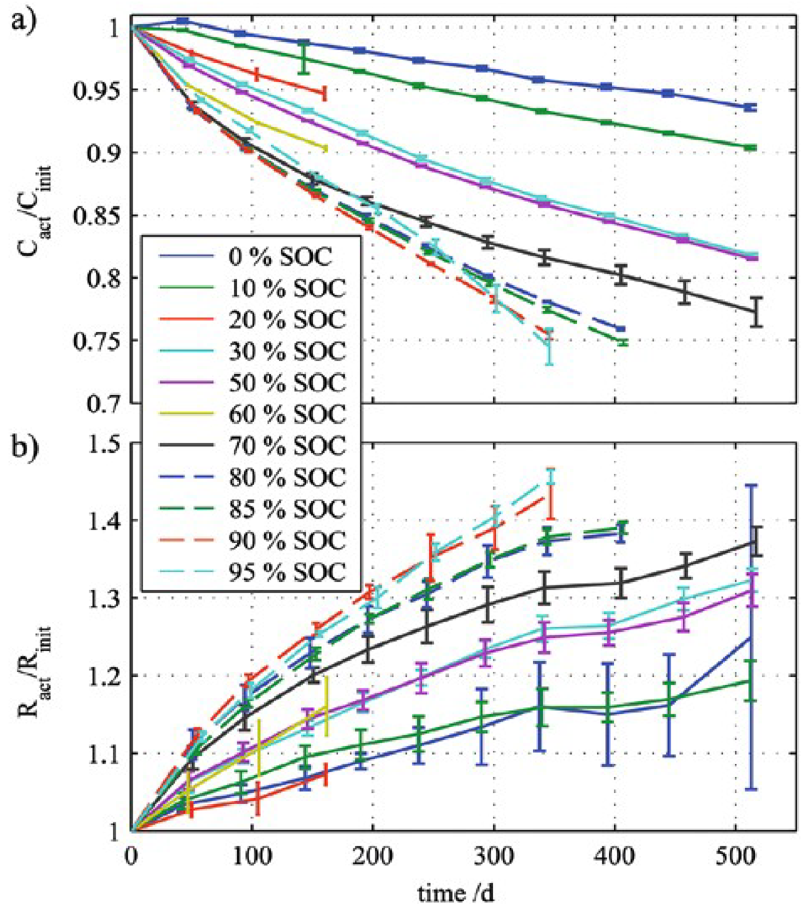
It is therefore crucial for transport operators to always establish optimal conditions both during the trip and during charging, and to operate battery systems as sparingly as possible. The charging management system (CMS) is responsible for planning and controlling charging processes, and can positively influence the technology's lifespan by taking the battery specifics into account correctly. The way in which the CMS works together with the dispatch as part of the depot management system (DMS) is also extremely important. Charging durations must always be taken into account when allocating vehicles to vehicle workings and charging stations in order to achieve optimal results.

The following article explains the ageing processes of batteries and describes the functions and advantages of a CMS in relation to battery ageing.

## Possible Causes for Electric Bus Battery Ageing

Lithium batteries are used in virtually all electric buses. There are various factors that influence the ageing of batteries: Voltages due to high states of charge and high temperatures usually lead to faster ageing than medium voltages or moderate temperatures. Voltage and temperature are physical quantities that describe the energy content of a system. The higher the energy content, the faster the associated parasitic reactions take place in the system. This can lead, for example, to charge carriers (lithium ions) being bound and no longer being available for the actual electrochemical reaction. In addition, covering layers can grow on the active materials. This means that the battery cells lose capacity while their internal resistance increases - even if the battery is not charged or discharged at all. This is referred to as "calendar life" because the battery's lifespan is limited even if it is not used at all.

However, if the battery ages due to charging and discharging, this is referred to as "cycle ageing" or "cycle life". The expansion of the active materials changes during charging and discharging, which leads to mechanical stress and ultimately to wear of the active materials. This can be compared to a piece of metal that is repeatedly bent back and forth: The greater the bending, the faster the material fatigues at the bending point. Depending on the depth of cycling - and depending on the cell technology - you can extract and recharge the capacity about 800 to 5000 times until the battery reaches its end of life. This is also called "full cycle equivalent". Lithium titanate (LTO), on the other hand, which is an active material for the negative electrode, has a significantly lower volume work than the "classic" anode material graphite. The corresponding cells can therefore achieve two to five times as many full cycle equivalents.




a) Normalized capacity over time and b) normalized resistance over time for calendar aging tests at 50 °C. For each SOC the average on three cells under tests is shown. The capacities for cells under same conditions have a great uniformity, while resistance increase varies a bit.

The figure shows the results of an accelerated ageing test to determine the "calendar life". For the test, battery cells of one type were stored at different states of charge (SoC) and otherwise constant conditions, that is not discharged and recharged .

Diagram a) shows the course of the remaining capacity ($C_{act}$) and diagram b) the course of the internal resistance ($R_{act}$) – in each case over the storage period in days. The available capacity decreased faster and the internal resistance increased faster, the higher the state of charge was, in which the cells were.

*Fig. 1: Results of a typical ageing test for battery cells (cell type: Sanyo UR18650E, cathode material: NMC, anode material: graphite), carried out at ISEA of RWTH Aachen University.*

## Influencing Battery Ageing

In order to slow the battery ageing to the greatest extent possible, initial attempts can be made to minimise the parameters mentioned above – i.e. temperature, stress, state of charge, and cycling. "Storage in the refrigerator" would accordingly ensure the longest battery life duration. However, because the purpose of the battery is to take in and then provide energy for propulsion and to power auxiliary components, and operation always has priority, "storage in the refrigerator" is not possible. Nevertheless, there are degrees of freedom that can be used – particularly via an appropriate charging management system – to operate the batteries as sparingly as possible. To minimise calendrical ageing, buses can be charged as late as possible, for example, and only enough to have a sufficient state of charge for the following vehicle working, which does not necessarily require 100% charge. This means that the batteries are only in high states of charge for as short as possible.

The charge capacity also always influences battery ageing. A high charge rate, for example, causes the battery to heat up. If the cooling system is not adequately constructed, and this leads to an uneven distribution of temperature, then parts of the battery pack will age particularly quickly. The quality of the battery pack and of the cooling system is therefore crucial. There are different cooling systems on the market, as well as battery systems of varying quality.

At the end point, vehicles are often charged with a high charge capacity. The charging duration is then around five to fifteen minutes. If the quality of the battery system is sufficient, restricting the charge capacity has little effect on such charging processes. In this case, the focus should be on ensuring operations. If charging takes place overnight at the depot, however, more time and therefore more flexibility is possible, and the charge rate can be correspondingly reduced.

Cycling the battery as well as the cycle depth should be orientated to the needs of operating the buses. If the electric bus system is solidly planned and constructed – meaning that the battery capacity is adjusted to the worst-case scenario – cycling is normally moderated anyway, because the worst-case scenario rarely occurs. It generally does not make sense to shorten vehicle workings beyond what is possible and thereby to accept higher vehicle requirements or other operating inefficiencies, merely in order to flatten the battery cycling.

### About the Author

**Philipp Sinhuber**, one of the managers of EBS ebus solutions GmbH, along with his team of engineers and software developers, is responsible for algorithms that predict energy consumption and help plan charging phase scheduling in IVU.suite. These algorithms ensure that electric buses are charged as sparingly, reliably, and cost-effectively as possible. In his time at the RWTH Aachen, he conducted more than six years of research in the field of battery system technologyfor electric buses. Since 2015 he has been advising transport operators who are transitioning to electric buses with ebusplan GmbH.

## Requirements for a Charging Management System (CMS) for Electric Buses

A CMS controls the charging devices – generally according to the Open Charge Point Protocol (OCPP) – and sets upper capacity limits for them within which the charging devices negotiate the actual charging processes with the vehicle and carry them out. The CMS allocates the capacity in such a way that different hard and soft goals are achieved. Hard goals include charging all buses in time for their next deployment, for example, as well as not overburdening components or the power grid connection. Maintaining a blocking period, during which no charging or charging only with low capacity can be carried out, is also a hard goal. A soft goal, on the other hand, is the minimisation of the peak capacity in order to reduce the network costs to be paid by the transport operator.

A good CMS recognises the deployed vehicles and their batteries, as well as the charging infrastructure used. It can therefore predict charging durations as well as specifically tailor the charging phases and thereby increase optimisation potential. Charging phases can be more tightly spaced and buffers as well as redundancies can be more deliberately scheduled at the points where it makes sense to place them.

Building on this, a good CMS offers transport operators the option of setting the control of charging phases specifically for bus operations. There are significant differences here from city to city and from one administrative district to another. One transport operator may require more buffers and reserves due to operational flows in the depot than another, for whom peak capacity reduction plays a significantly more important role. A good CMS therefore brings these different influences together and optimises the charging schedules according to the specific local general framework, which can be set by the user.

For reasons of cost efficiency, the power grid connections in depots are generally not dimensioned to be capable of simultaneously charging all vehicles. The charge capacity resource is therefore limited and must be allocated according to priority. Charging requirements and departure times must be taken into account to maximise operational stability. The CMS receives the buses' departure times and the minimum state of charge required from the depot management system (DMS) and therefore knows how much energy must be charged and how long the charging will take. The CMS must additionally take into account the buses that are still en route and receives for them a prognosis of the expected state of charge when they enter the depot. Furthermore, the DMS must know how much energy the bus uses and how much energy may need to be charged at end points ("opportunity charging"). A good CMS is therefore fully integrated into the system landscape and is above all application-specific, that is, tailored for bus operation, which varies significantly, for example between operating at a motorway service area or at a parking garage.

## CMS Functionality Relevant for Batteries

In the overall system described above, the battery also plays an important role. It is not only the passenger compartment, for example, that must be preconditioned before departure, but also to a certain extent the battery itself. This is also controlled by the CMS and can be planned by the dispatch manager via the DMS. Furthermore, the CMS must also provide capacity for further secondary consumers during charging as well as for "balancing". This equalising of the stresses of the different cells in the battery system is necessary for all lithium batteries from time to time in order to keep the battery capable of performing and to avoid unnecessary ageing. For some batteries, this requires that power be supplied by the charging device.

The following figures 2 and 3 show a schematic example for three buses. The marker "AN" represents the arrivals at each charging station. The marker "AB" symbolises the later, renewed exit from the depot. The height of the coloured bars depicts the charge capacity assigned to the vehicle (by the

CMS), while the width depicts the duration of this capacity assignment. The blocks symbolise a simplified form of the "chargingSchedulePeriod" in accordance with OCPP and the black curves depict the expected course of the state of charge.

Figure 2 shows the case of uncontrolled charging. All buses begin charging directly after arrival at the charging station. Correspondingly, in the time range in which the blue and green charging blocks overlap, a high peak capacity is to be expected. The batteries of both buses above are therefore quickly completely charged (SoC 100 percent) and remain for a long time in a fully-charged state.

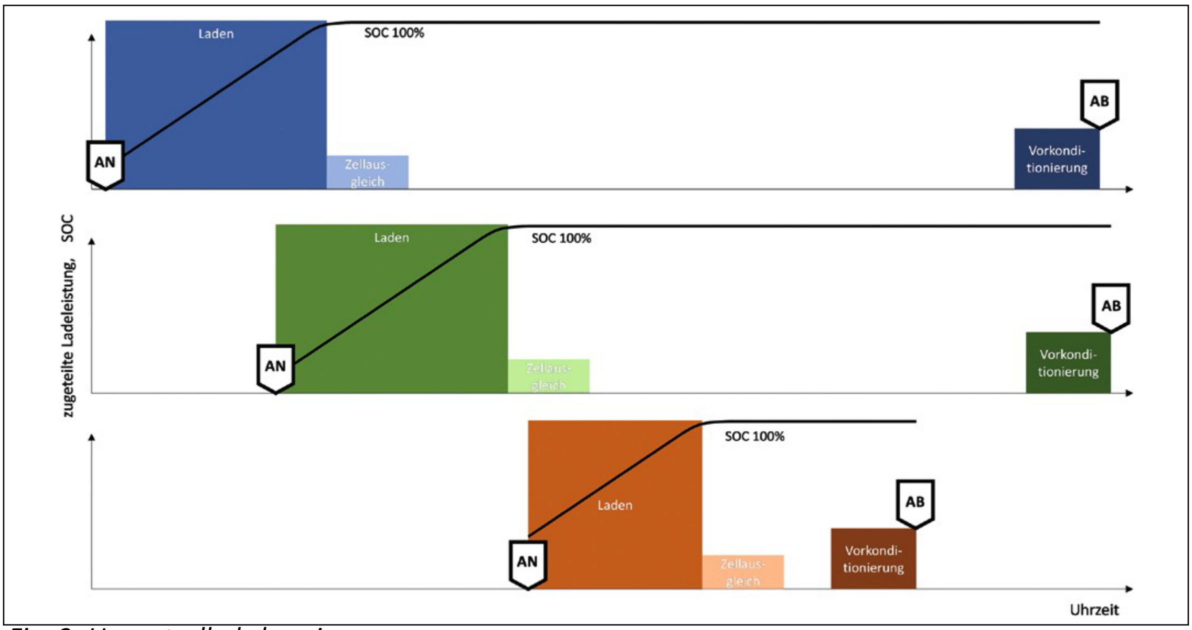


*Fig. 2: Uncontrolled charging*

Figure 3 then shows the case of intelligent charge phase scheduling. Here, not only is simultaneous charging kept to a low rate in order to avoid load peaks, and the capacity distributed, but also the vehicles are prioritised according to their departure times and charge requirements when allocating capacity. Through better use of standing times, the charge capacities are lowered. This can be recognised from the flatter blocks and the state of charge courses, which increase more slowly. This somewhat reduces the losses of the charging infrastructure because the losses disproportionately increase with increasing load – for example in the transformers, sub-distributions, and supply lines. But there are also effects on the batteries: For example, the decrease of the charge capacity from 120 kW to 60 kW means, roughly estimated, a halving of the charge rate. For contemporary battery packs, which for solo buses are generally above 300 kWh, even 120 kW is a low charge capacity. A decrease would have little effect given corresponding battery system quality. On the other hand, the effect of the batteries reaching the fully charged state significantly later, and therefore remaining at high states of charge for shorter periods, can play a larger role (fig. 1).

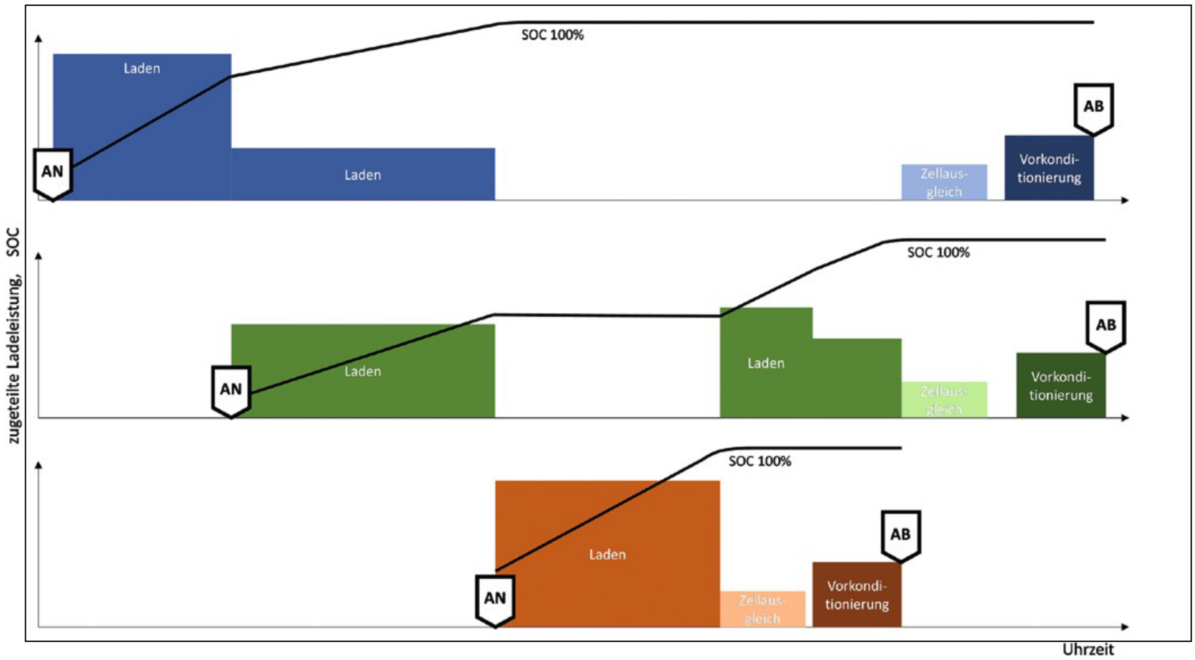



*Fig. 3: Charging with load smoothing which also preserves the batteries*

In Figures 2 and 3, it is assumed for simplicity that the buses are fully charged. To further preserve the batteries, it is possible to charge them only up to the minimum state of charge required for the following vehicle working.

## Prospects

With knowledge of charging needs and charging behaviour, as well as the guidelines of the operator concerning necessary buffers and optimisation goals, a good CMS can also take the influences on battery ageing mentioned above into account, charge batteries in the most sparing way possible, and monitor charging progress.

If further information on the state of the vehicle, such as the battery temperature, is also available, security features can be implemented. Given current discussion in the industry of the causes of fires on electric buses and strategies to avoid them, the CMS can represent a further layer of security – in addition to the security mechanisms of the vehicle and the battery management system – because it monitors the battery temperature while the bus is driving. To the extent that the battery temperatures of all vehicles are provided by the charging interface, it would even be conceivable to incorporate the battery temperatures into the charge phase scheduling and to be able to redistribute charge capacity early. A corresponding integration into the DMS would even enable dispatch-related decisions to take this information into account.

**Literature:**

[1] J. Schmalstieg et al./*Journal of Power Sources 257* (2014), 325 – 334.