Charging behavior of lithium iron phosphate batteries

Whitepaper

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1 Technical background: LFP battery

1.1 General information

Development of battery storage systems has made great progress in recent years and there are now various types of batteries to choose from, depending on the application. One type is the lithium iron phosphate battery, also known as the LFP battery or $LiFePO_4$, which is manufactured by BYD and others.

1.2 Advantages and disadvantages of the LFP battery

The advantages and disadvantages of lithium iron phosphate technology in terms of charging behavior, safety and sustainability are listed below.

The extraction of raw materials and the associated environmental damage are an important aspect when it comes to the production of batteries. Cobalt is particularly often the focus of attention. It is therefore important to note that this element is not used in the production of $LiFePO_4$ batteries. This is one advantage over lithium cobalt (III) oxide batteries such as NMC or NCA. Another factor is the issue of safety. $LiFePO_4$ are robust and offer a high degree of safety, which means the probability of thermal runaway, where damage to one cell also affects the other cells in the storage system, is significantly lower.

These batteries are high-current capable, i.e. they have a high charging and discharging capacity, which shortens charging times. Furthermore, when installed and used correctly, the battery has a high level of efficiency and a long service life.

Lithium iron phosphate batteries have a low self-discharge rate of 3-5% per month. It should be noted that additionally installed components such as the Battery Management System (BMS) have their own consumption and require additional energy.

The low energy density of LiFePO4 means that more cells must be installed for the same output compared to other battery types, such as lithium cobalt (III) oxide. This technical basis results in a higher weight and volume.

The voltage curve, i.e. the voltage change during charging and discharging, is very flat with this cell chemistry. This makes it more difficult to determine the current state of charge (SoC), as this must be calculated based on the voltage under the influence of temperature and cell ageing. Even small changes in voltage, such as those due to temperature, can influence this value.

1.3 Conclusion: LFP battery in comparison

Lithium iron phosphate batteries are fast-charging, high-current capable, durable and safe. They are more environmentally friendly than lithium cobalt(III) oxide batteries. Their high discharge rate, long service life and safety make them ideal for use as home storage batteries in combination with PV systems.

2 Determining SoC

2.1 Definition of SoC

State of Charge (SoC) is a characteristic value for the state of charge of a battery. It describes the currently available capacity in relation to the nominal value and is given as a percentage. The nominal value is influenced by the state of health (SoH) of the battery. The SoC is calculated via voltage, whereby factors such as temperature, cell aging (SoH), current flow and charging behavior also play a role and influence the accuracy of the calculation.

2.2 Procedure for determination under ideal conditions

Starting from a reference point (e.g. SoC=100%), the battery is discharged at a constant current until it reaches the final discharge voltage or its own protection voltage. After discharging there is a pause during which the battery's open-circuit voltage is set. Once this voltage is reached, all overvoltages in the system caused by the discharge have dissipated.

The principle is then reversed, and the battery is charged to full capacity with a constant current. After the battery is fully charged, there is another pause until it is discharged again to the final discharge voltage. During this discharge, the current, voltage and time are recorded.

The resulting integral of discharge time, current and voltage is obtained relatively easily in the laboratory and then implemented in a battery management system in the form of a look-up table. Depending on the voltage present in the system, the BMS can use the stored values to determine the current residual energy and set this in relation to the total capacity. This ratio describes the SoC.

2.3 BYD statement on charging behavior and determining SoC

In the BYD Battery-Box Premium HVS/HVM Service Guideline and Checklist, Version 1.5,[1] BYD gives the following instructions for determining SoC in Chapter 2.5 SoC & charging logic:

"*The state of charge of an LFP battery cannot be measured. It is a calculated value. In general, the state of charge of a battery is calculated using the voltage, but other factors such as temperature, current flow and*

[1] https://docs.eft-systems.de/download/DOC-00048&_lang=en

charging behavior also play a role. The calculation of the state of charge is generally more precise if the battery regularly sees full cycles. Every now and then an SOC correction / calibration may occur. That is normal."

With reference to determining SoC during initial commissioning, BYD states the following in the "BYD Battery-Box Premium HVS/HVM Service Guideline and Checklist" (version 1.5):
"A new BCU might show a different SOC at the beginning (mostly 50% / 30% / 0%). However, this is only to be understood as a placeholder value, as a new BCU cannot measure the SOC of modules. As soon as the system starts to run (charge/discharge) the SOC detection is corrected gradually. The SOC calibration is completed at the latest after a full cycle."

2.4 Conclusion: determining SoC

Since precisely determining the SoC is difficult to implement in everyday practice due to the time required, less-than-ideal framework conditions and many other factors (temperature, charging behavior, cell aging (SOH), manual battery control specifications, etc.), calculation of the SoC is always only approximate and can deviate from the real value by several percentage points. The system therefore makes corrections from time to time. Especially in the darker months, the battery does not experience full charging cycles, which leads to greater inaccuracy in the SoC calculation and to short-term capacity losses. Normally, the calculation regains accuracy after 5-8 consecutive, full cycles. In the summer months, when the battery regularly runs through full cycles, the system can perform the calculation more often and therefore more accurately. SoC jumps will become less frequent or cease.
During recommissioning, several full cycles are also necessary for the BMS to carry out the SoC calibration and balance out the differing cell voltages present in the battery modules due to the varying states of charge of the cells.

3 Examples in Fronius Solar.web

The Solar.web online monitoring portal from Fronius provides energy balances and lets customers monitor their PV system with Fronius components. The energy balances contain curves for the battery state of charge as well as data on the energy charged and discharged in the battery. The data are 5-minute average values which are retrieved from the inverter. The battery's SoC is calculated exclusively by the battery's BMS and transmitted to the inverter. This is calculated by the battery management system based on the voltage of the battery cells. Two examples of behavior with inaccurate SoC calculation due to a lack of complete charging cycles are discussed below. In all examples, the storage systems and PV systems were tested for full functionality.

Example 1:

Here, a rapid increase (Fig. 1 and 2) and a rapid decrease in the SoC (Fig. 3 and 4) can be observed in the energy balance, although no power is flowing to or from the battery. This is an SoC jump: a phenomenon in which the storage system transmits an unrealistic SoC to the inverter. In the course of discharging, the behavior regulates itself and the SoC briefly drops to another unrealistic value (0%) and then returns to a real value. When comparing the energy supplied and the energy removed from the battery, it becomes clear that these correspond fairly closely, but do not correspond to an SoC of 100%. Figures 1 and 2 show the energy supplied in the green diagram, Figures 4 and 5 show the energy removed in the green diagram.

Figure 1:

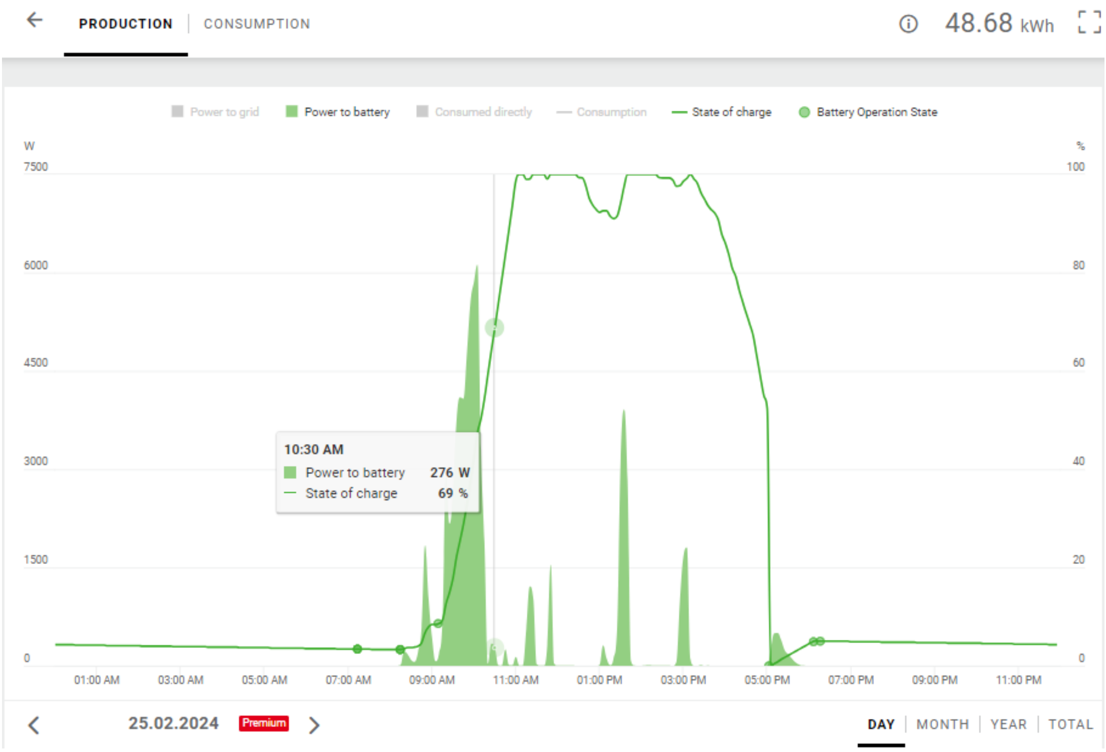


Figure 2:

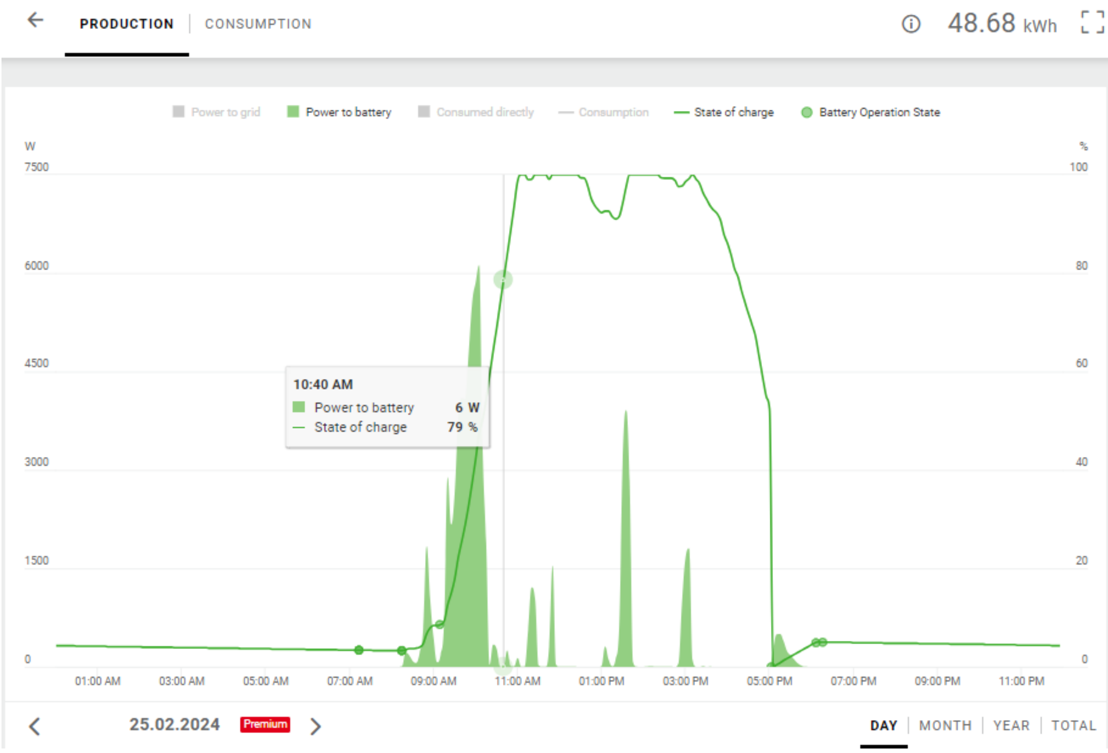


Figure 3:

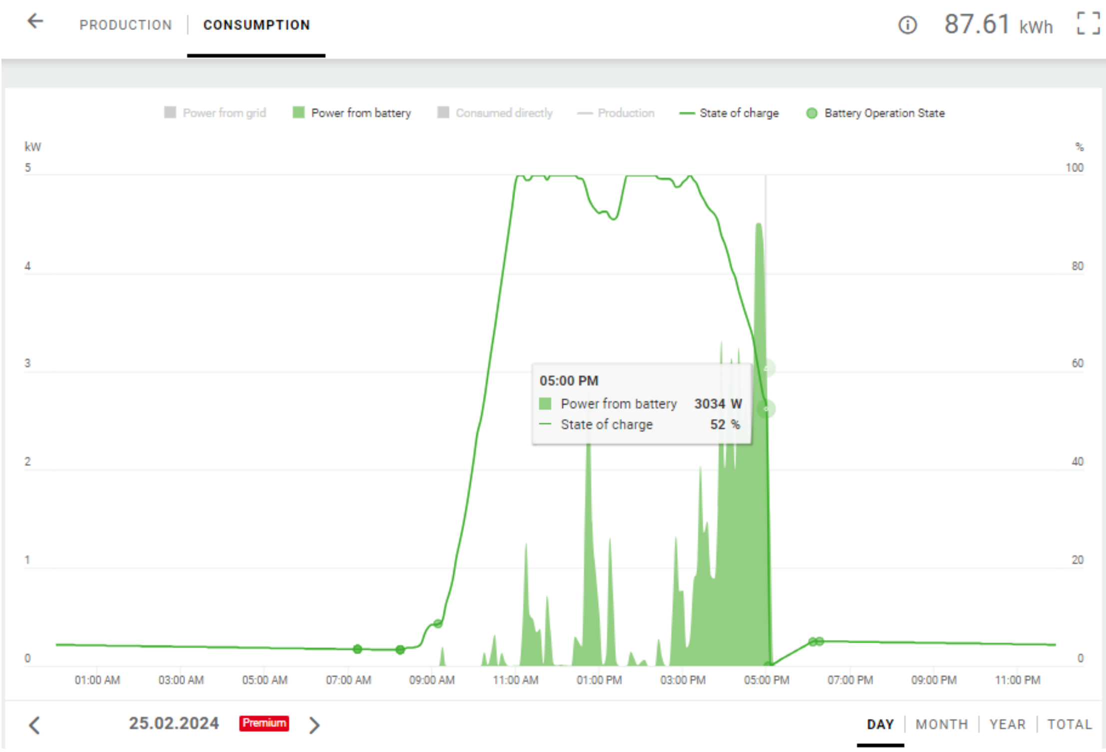
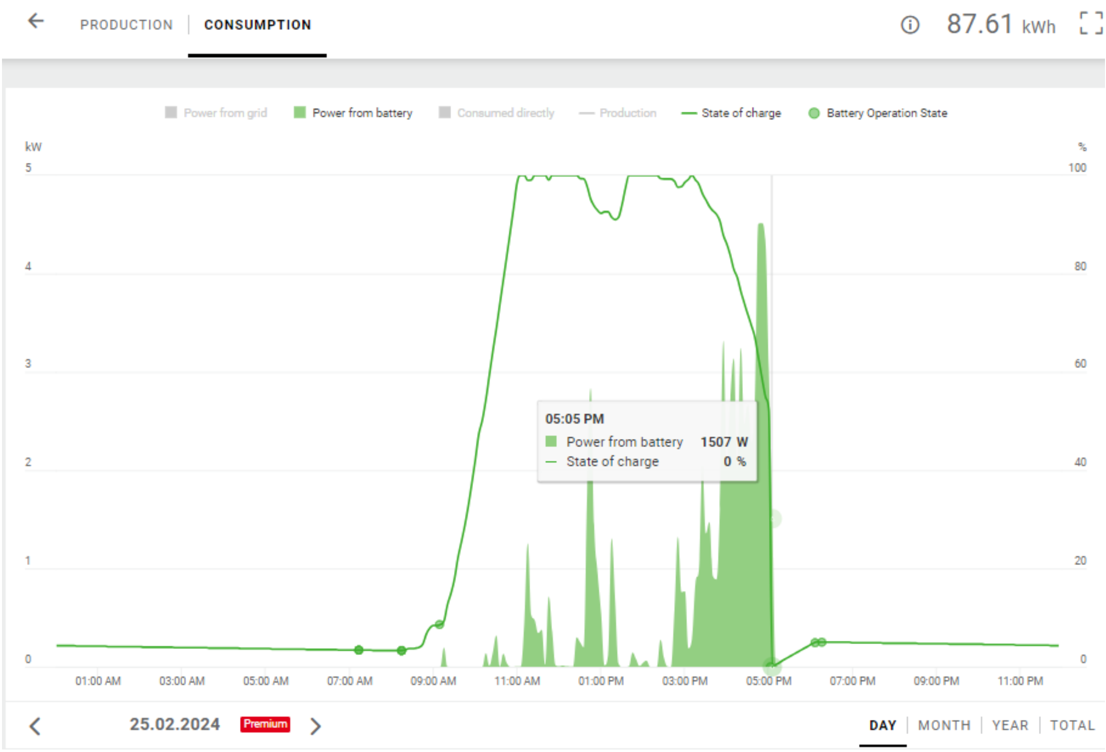


Figure 4:



Example 2:

In this case, no SoC jumps can be seen over the course of the day (Fig. 5), but the SoC of the battery is still displayed at 100%, although the amount of energy charged does not correspond to the capacity of the battery (in this case BYD HVS 7.7 with a usable capacity of 7.3 kWh). Figure 6 shows the amount of energy supplied on Feb. 1, 2024, for charging from 5% to 100% in kWh. This daily curve shows 1 of 2 full charges in the 20-day period. For comparison, the same charging quantity from 5% to 100% is shown in Figure 7 with a correct calibration, which is recorded for daily charging and discharging.

Figure 5:

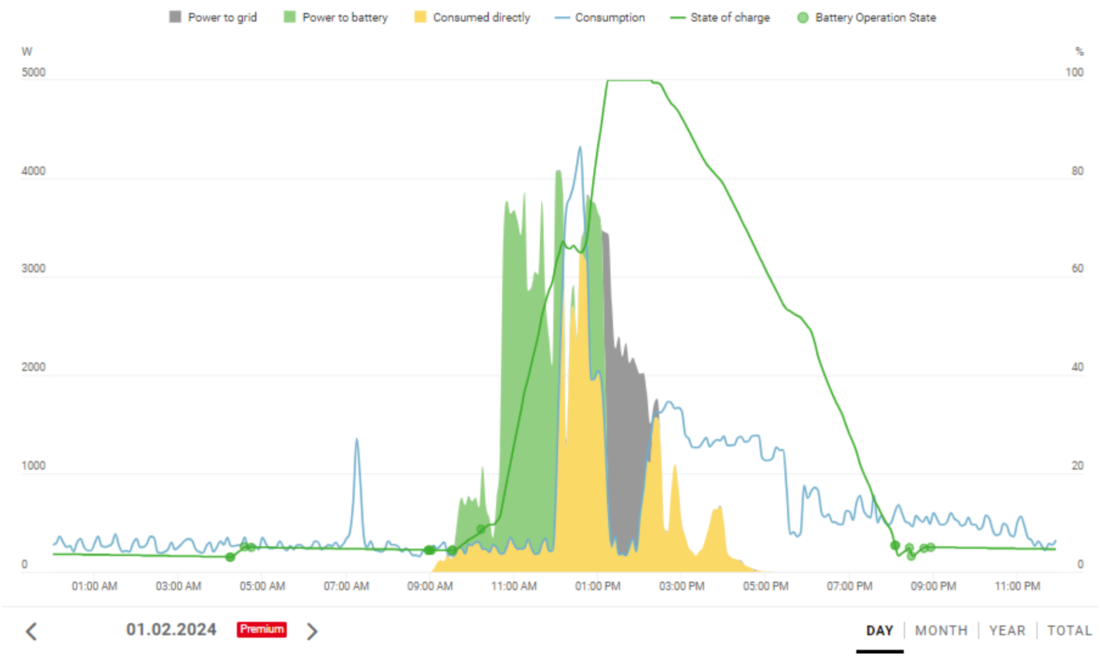


Figure 6:

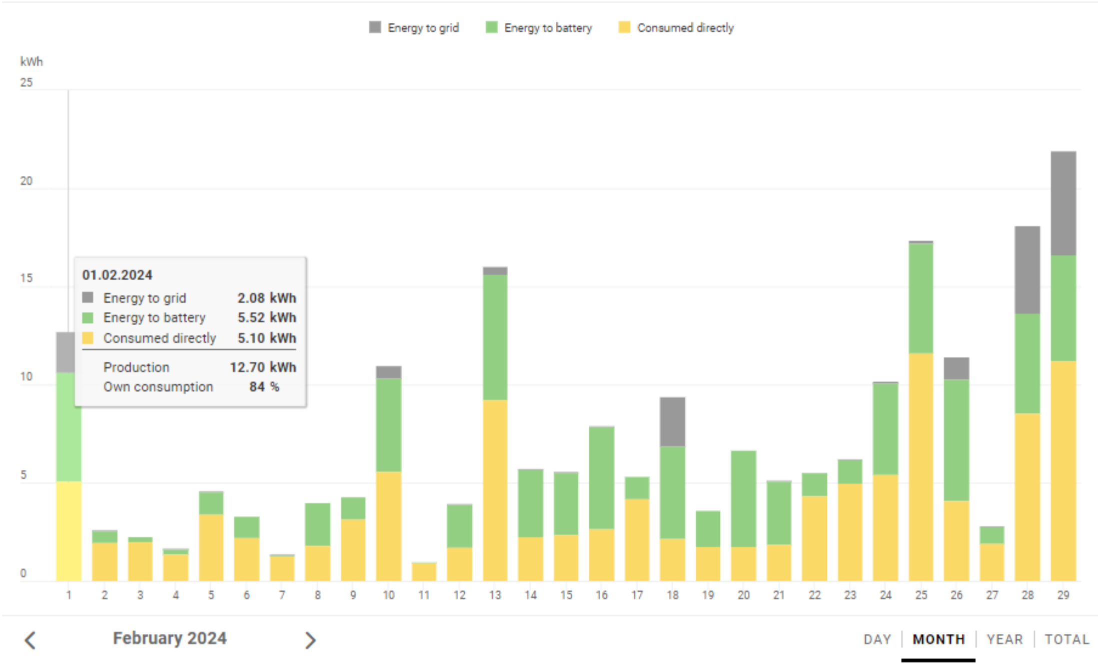
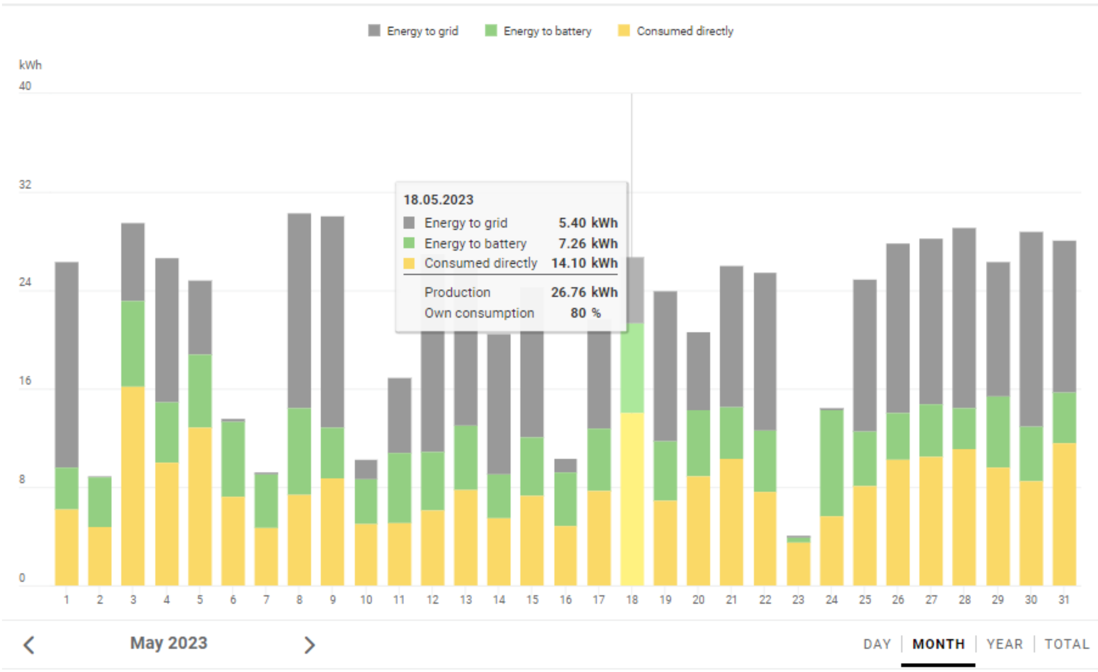


Figure 7:



4 Summary

The charging behavior of a lithium iron phosphate battery is an aspect that both Fronius and the battery manufacturers are aware of, especially with regard to calculating SoC and calibration in months with fewer hours of sunshine. Due to the high volume of inquiries, we have analyzed many battery storage systems in this regard. Changing weather conditions and fewer hours of sunshine in the winter months result in more partial charging cycles, which have a negative impact on charging behavior. In some regions of the world, customers experience snow-covered roofs for weeks on end, during which storage systems are not used and remain in energy-saving mode. In the winter of 2023/24, partial charging cycles increased and significantly exacerbated the SoC issue. The examples and behaviors described in this document can frequently be observed in the winter months from late fall to spring. In these cases, it will take significantly more full charging cycles before the display in Solar.web regains an accurate perspective. In spring, however, the systems should recalibrate themselves, operate at full capacity, and make the entire capacity available.

With an inverter from Fronius and a battery from BYD, you have chosen one of the best and safest systems on the market, as shown once again in the 2024 Energy Storage Inspection by HTW Berlin.[2] Please also see the following images with the results of the 2024 Energy Storage Inspection (Figure 8) and the safety test carried out by BYD under extreme conditions, in which the battery modules did not exhibit any explosive or flammable properties in the event of fire, perforation or strong pressure effects (Figure 9). [3]

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[2] https://solar.htw-berlin.de/studien/stromspeicher-inspektion-2024
[3] Presentation from BYD

Figure 8:

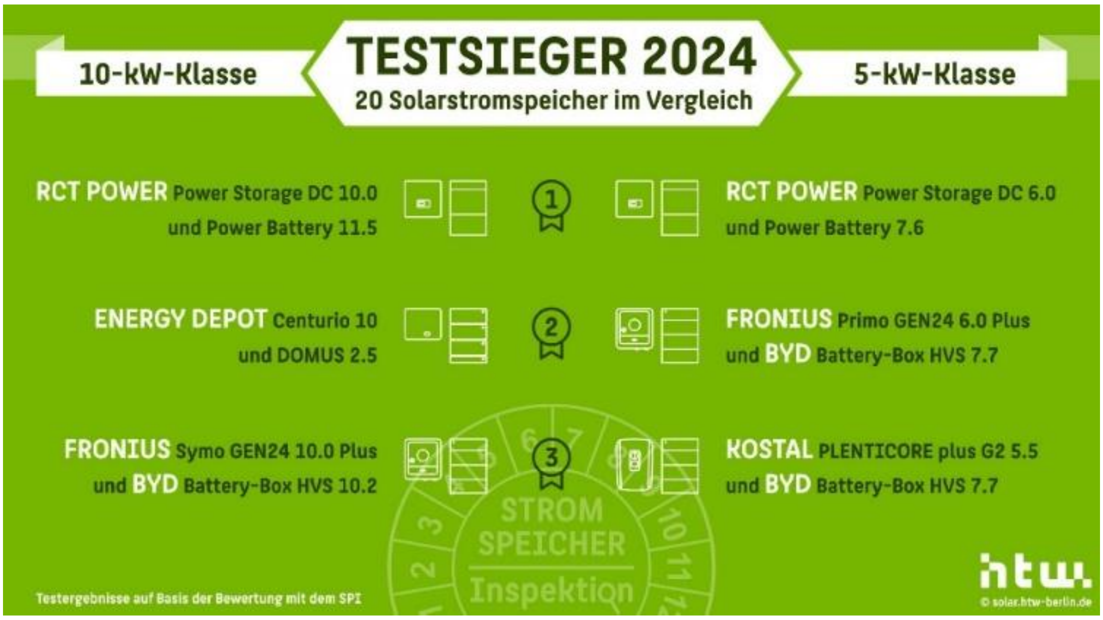

Figure 9: