Battery Management in Stand-Alone Systems

SMA inverters impress with precise determination of state of charge

Summary

Stand-alone power supplies can be set up in a very easy manner using the Sunny Island inverters developed by SMA. The Sunny Island is fed from the renewable energy sources that are available on site – such as electricity from photovoltaic plants. This energy is stored in accumulators until it is needed. Hence the reliability and efficiency of the accumulators play an important role.

Until now the accumulator has been considered as the most risk-prone component in stand-alone systems. This can particularly be attributed to inaccurate battery management. The difficulty here is that the state of charge of the batteries is difficult to measure. The ability to accurately ascertain the state of charge is a basic requirement for correct operation and thus maximum battery service life. If the battery management system is not working accurately, then plant operators will have to replace the batteries at a relatively early stage.

With the Sunny Island battery inverters, SMA offers the optimum solution: the special battery management is based on the exact determination of state of charge. By combining the three most common methods of state of charge determination, these devices achieve a measurement accuracy of more than 95 percent. Thus overcharging and deep discharging of the accumulators is safely avoided. A clear advantage: the battery management system developed by SMA ensures that the battery lifetime stated by the manufacturer is also achieved in off-grid systems. In comparison, competing devices often only realize half of the lifetime stated by the manufacturer. The SMA system ensures that individual accumulators no longer have to be replaced unnecessarily and reduces high maintenance costs. Furthermore, accurate state of charge determination enables an optimum exploitation of the battery capacity. This means that smaller and thus more cost-effective batteries can be used with the same performance and longer lifetimes.

Accumulators in Stand-Alone Power Supplies

The Sunny Island system

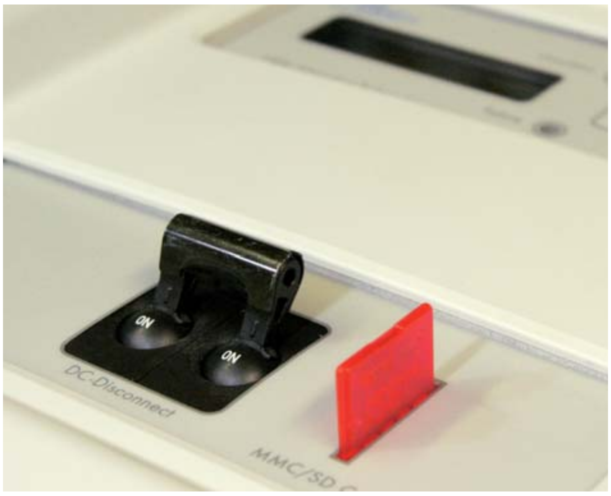
Stand-alone power supplies can be set up using the Sunny Island battery inverters developed by SMA. The Sunny Island is fed from the renewable energy sources that are available on site – such as electricity from photovoltaic plants, wind or hydroelectric power stations. Connected to a battery unit in which the energy is stored until it is actually needed, the Sunny Island forms a stand-alone AC grid which meets the highest quality standards.

This technology makes it possible to provide power to most of the 1.6 billion people still living without electricity today. Sunny Island systems are being used more and more often in remote areas where connection to the public power distribution grid is difficult or completely impossible. Hence the stability of the stand-alone grid system is important, as is the smooth and efficient interplay between battery and inverter.

Is the accumulator a risk factor?

The rechargeable battery, also known as the accumulator, is considered to be the most risk-prone component of stand-alone systems. Above all this is due to the state of charge of batteries is difficult to measure and the calculated lifetime is often not achieved. For plant operators, this means that the already expensive accumulators have to be replaced at a relatively early stage in comparison to other components. To avoid this, accumulators with a greater capacity than is actually necessary are often installed in stand-alone power supplies. This does indeed give the system operator more leeway, although not necessarily a longer accumulator lifetime. Even though the investment costs increase, the end of life of an accumulator is still reached after 10 to 15 years at most – or even less in reality.

However, this method is also anything but cheap, since the price of batteries increases almost in direct proportion to their size. Therefore, SMA is working continuously on the optimization of state of charge recognition.



The Accumulator:
Stores Energy – Provides Energy

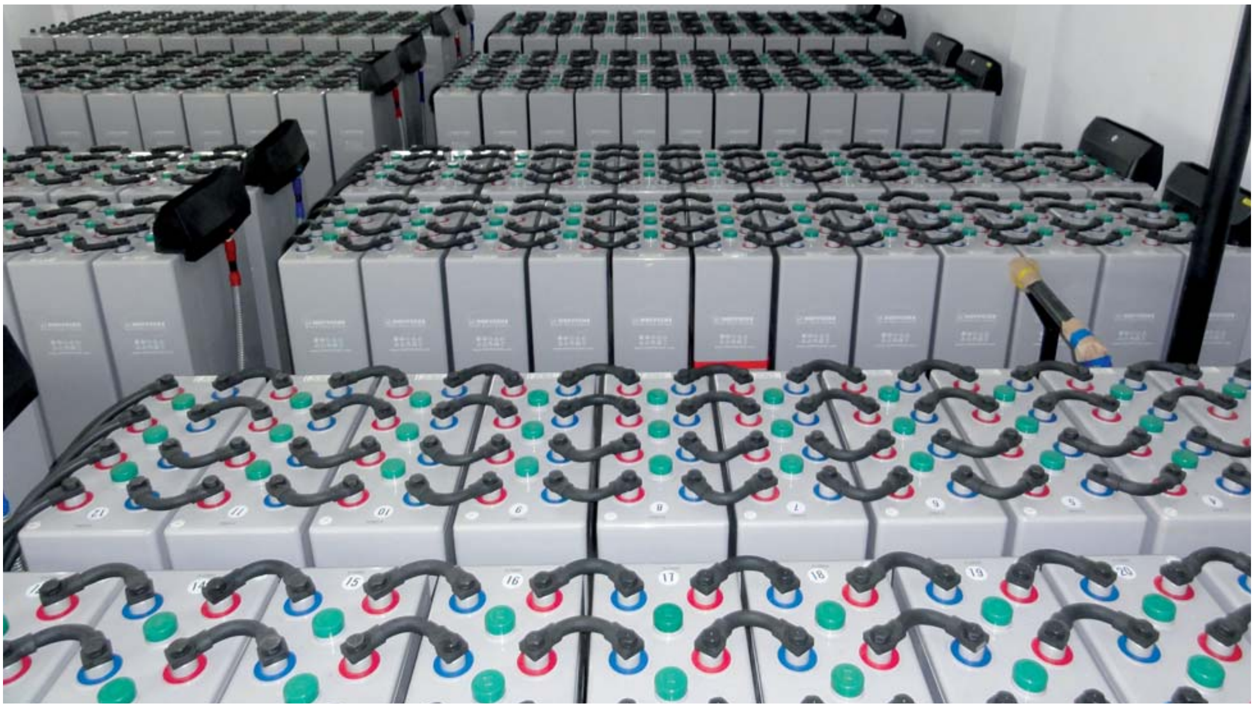
The conversion of energy

The accumulator stores electrical energy in order to be able to supply it when needed. This takes place on the basis of an electrochemical system: as the accumulator charges, the electrical energy is converted into chemical energy. The accumulator stores this chemical energy. When a load is connected or started, it converts this stored energy back into electrical energy and provides it for use.

The conversion of electrical energy into chemical energy has two decisive advantages: firstly, chemical energy has a higher energy density and thus comparatively more energy can be stored in a smaller volume. Secondly, the losses which occur during the storage of chemical energy via self-discharge are lower than those occurring during the storage of electrical energy.

Electricity on the go, at home and in off-grid regions

Accumulators are used wherever grid-independent operation of electrical devices is necessary or desired. They are used in small utility objects such as electric razors, mobile telephones or MP3 players, but also in large off-grid applications such as a stand-alone power system. Often this kind of system is the only way of supplying power to homes or areas that have no access to a power distribution grid.



Capacity and State of Charge

The capacities of a battery

The term "capacity" refers to the maximum amount of charge that a fully charged accumulator can provide. It is indicated in ampere hours (Ah) and depends on the discharging process, i.e. on the discharging current, the final discharge voltage of the accumulator (the voltage at which discharging is stopped), the temperature and the age. Accordingly, different discharging processes – for example with constant current, through constant resistance, or with constant power, but primarily different discharging currents – lead to different accumulator working loads.

A basic distinction is made between two different capacities: the nominal capacity, i.e. the capacity of a new battery according to the manufacturer's specifications, and the actual capacity, which takes both aging and temperature into account.

The state of charge

The state of charge of an accumulator, which is also called "SOC" for short, provides an indication of the amount of charge that is currently available. The state of charge is given as a percentage, and so a battery with a SOC of 100 percent is fully charged. The battery is empty if the value is 0 percent. Lead-acid accumulators should not, however, fall below a value of 20–40 percent otherwise dangerous deep discharge occurs. This significantly reduces the service life of the battery or could even destroy it outright.

The state of charge of a battery can in fact be based on the nominal capacity of the accumulator, but does not then give a realistic indication of the actual available amount of charge since this depends on further parameters such as temperature, aging and the history of the accumulator. This is why the SMA indication of the state of charge is based on the actual capacity and thus takes these parameters into account.

The battery charger

A charge controller controls and monitors the charging and discharging of accumulators. Its main task is to prevent overcharging and deep discharging. This can in the simplest case be realized by limiting the charging voltage. More complex charge controllers use more parameters for control such as temperature, time, or charging current. A charge controller can be built into a stand-alone power system as an individual component or it can be integrated into the inverter itself, as is the case with SMA Sunny Island inverters.

No Battery Lives Forever

Why determine the charge state?

The service life of accumulators depends on both how they are charged and discharged, and therefore on the precise determination of state of charge. The most reliable way to prevent a deep discharge while an accumulator is discharging, and thus to increase its service life, is by ascertaining the actual state of charge – since in the event of a deep discharge, chemical processes which cause considerable aging occur within the accumulator.

The causes of battery aging

1. Sulfating
The normal discharge reaction in a lead-acid battery causes the conversion of lead and lead dioxide into lead sulfate. This process leads to a reduction in the concentration of sulfuric acid within the accumulator and thus to an increase in the solubility of the lead sulfate. During a deep discharge, sulfate crystals form that are so large that they can no longer be dissolved. Thus, they are no longer available for the reversible process. This activity is referred to as sulfating.

2. Corrosion

During a deep discharge or an overcharge, the lead grids within the accumulator react with the sulfuric acid more intensively. In the long term this leads to the corrosion of the grid: the cross-sectional area of the grid reduces and thus the grid resistance increases. This causes a considerable reduction in the conductivity of the accumulator over the course of time. A deep discharge aids this process and causes premature aging of the energy storage systems.

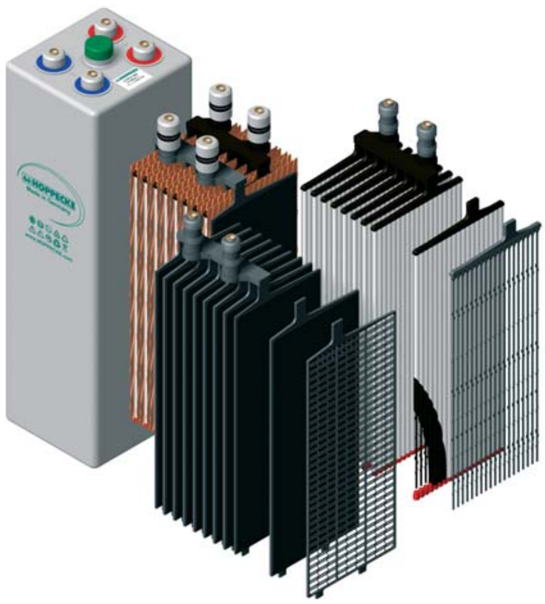
3. "Divergence" of the cells

No two accumulator cells are the same – even if they look identical, have the same specified nominal capacity and are discharged in the same manner. Their behavior can differ – even if only slightly – during discharge. Thus, the "weak" cells in a battery structure reach a state of deep discharge earlier, which means that they age faster than other cells due to sulfating and corrosion. Since the difference between the individual accumulators increases over the years, this phenomenon is referred to as "cell divergence".

At this point battery temperature shall also be mentioned as another factor that influences aging since high temperatures promote both sulfating and corrosion. This, however, is a phenomenon which even an intelligent battery management system has no control over.

The lead-acid accumulator

The type of accumulator used most often in stand-alone grid systems is the lead-acid accumulator. When charged, it consists of lead oxide (PbO_2) at the positive pole and finely dispersed porous lead (spongy lead) at the negative pole. Sulfuric acid (H_2SO_4) is used as the electrolyte – electrolytes are materials which conduct electrical current when voltage is applied. Although lead-acid accumulators are relatively heavy and have an energy density which is low for electrochemical storage systems they are, however, reliable and low-priced. Probably the best known application is the starter battery for motor vehicles.

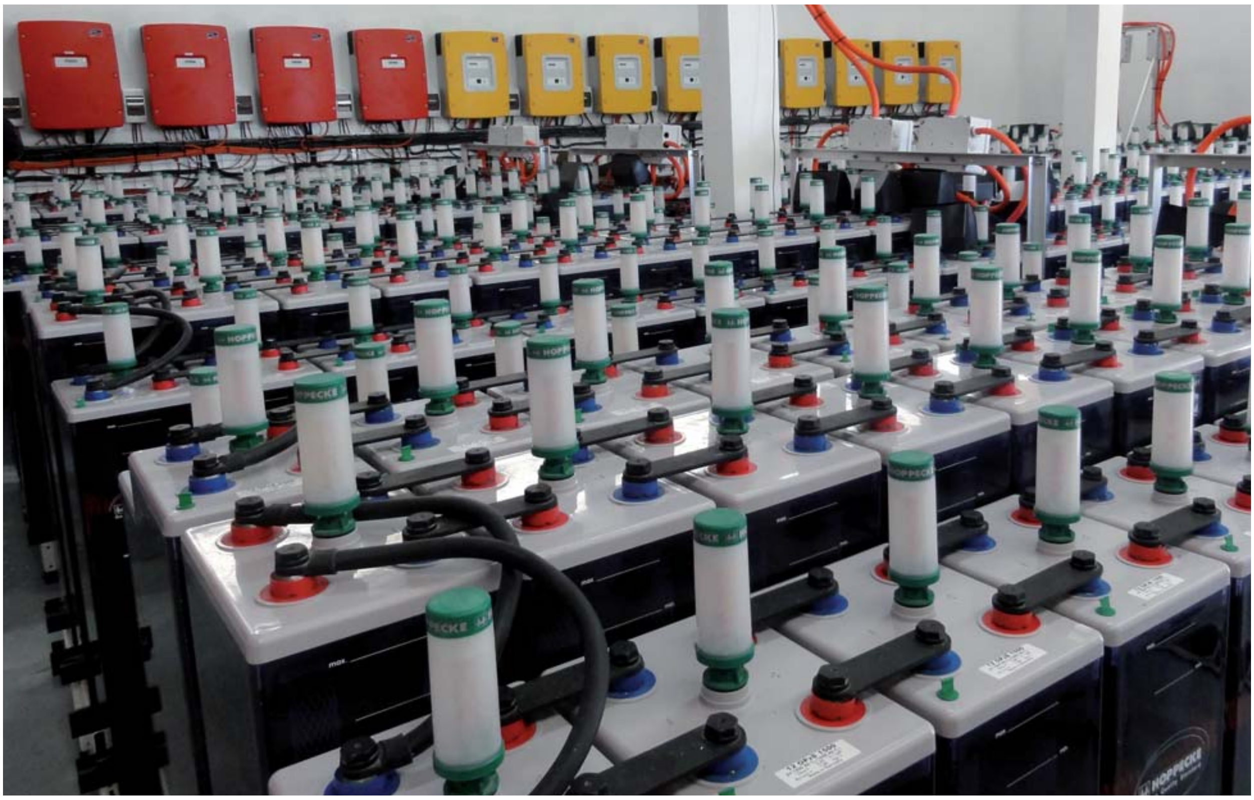


Methods of Determining State of Charge

Battery monitoring through voltage measurement

There are various ways to prevent both an overcharge and a deep discharge of accumulators. The simplest and most often used method is the specification of a final charge voltage and a final discharge voltage. With this, the voltage is constantly adjusted after the final charge voltage is reached. The discharging process ends once the accumulator reaches the defined threshold. Since the battery voltage can be measured easily, this method is logical. This is, however, not suitable for protection against deep discharging since the voltage is not only dependent on the state of charge, but also on the actual load of the accumulator. Thus, discharging is stopped either too early or too late.

In addition, the open-circuit voltage of a battery can be used to gauge the state of charge. It is to be noted here that the battery may not be charged or discharged for a period of several days. Furthermore, the relationship between state of charge and open-circuit voltage is very different from battery to battery.



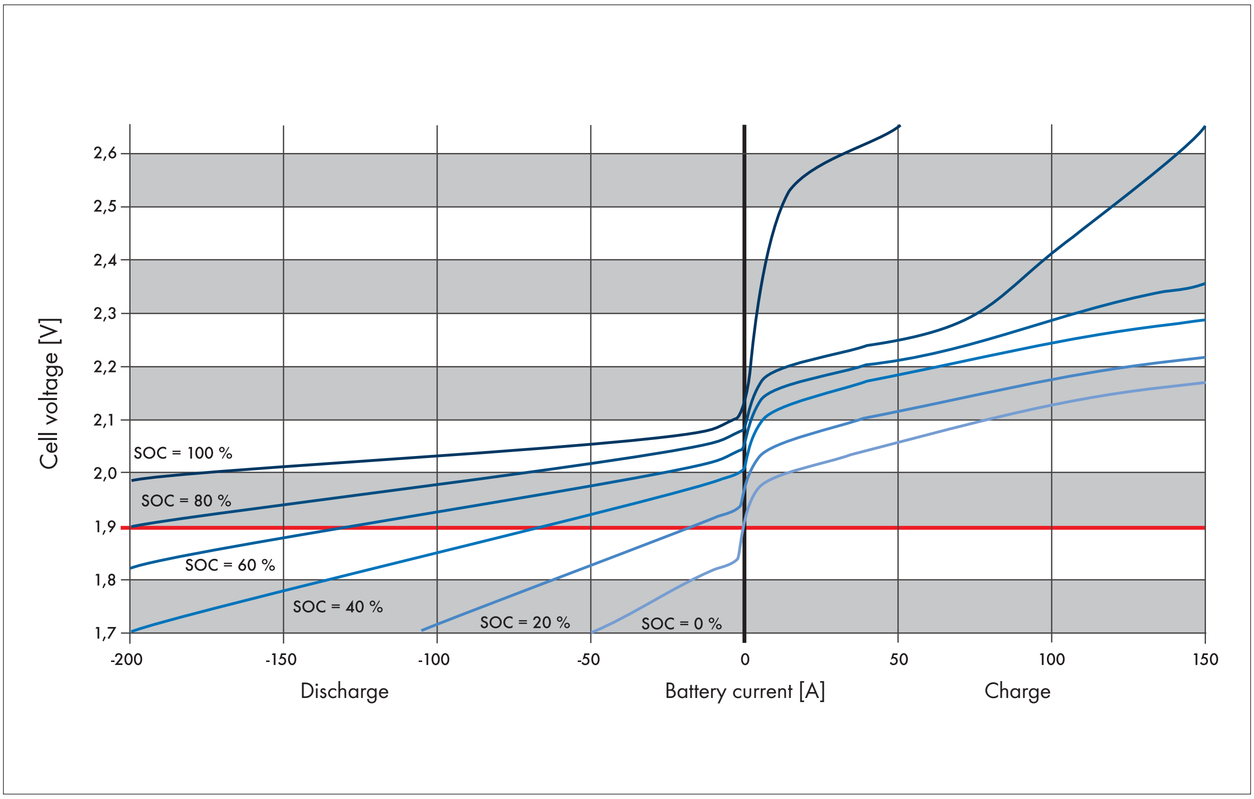
Current-voltage models

So-called current-voltage models incorporate both the voltage and the battery currents when calculating the state of charge. Thus, the dependence of battery voltage on charging- and discharging currents is taken into account and it is possible to determine the state of charge somewhat more precisely than when measuring voltage alone. Nevertheless, these models are also unable to accurately determine the state of charge since they ignore important factors such as aging, temperature and discharge profile. Hence, significant errors of more than 50 percent cannot be ruled out in determining the state of charge.

Balancing of the current

A third method of preventing overcharging and deep discharge is balancing the current. This involves measuring and adding the current flowing into and out of the accumulators. Necessary requirement for this method: the battery must be full at the beginning of the balance and its total capacity must be known – this is the only way to determine the state of charge.

The difficulty with this method is firstly the non-measurable secondary reactions within the battery and secondly the required level of accuracy when measuring the current. This accuracy decreases as the amount of time since the last full charge increases, because the measurement errors – regardless of how small they may be – are also incorporated into the balance equation. Thus, devices based solely on calculation of the charge balance are not suitable for PV plants, since it is often here the case that long periods of time pass without full charging.



Current-voltage diagram of a 400 Ah battery in the current-voltage range of Sunny Island 5048

SMA Determination of State of Charge

Precise

The Sunny Island inverters SI 2012/2224/5048 and the Sunny Backup inverters SBU 2200/5000 are capable of determining the state of charge of "their" accumulators very precisely. For this, SMA has combined the strengths of all three of the determination methods presented here. The balance calculation method is in the foreground, i.e., the measurement of the in- and out-flowing current. As this method would be relatively unreliable by itself, especially for PV plants integrated in stand-alone grids, it is supplemented by a current-voltage model in certain situations. These voltage measurements are performed for example at night, when little current is flowing out, and added to the balance equation. As a result the Sunny Island inverters achieve measurement accuracies of more than 95 percent.

Adaptable

The automatic adjustment of the state of charge determination to the battery type, aging, and temperature enables great precision – even under extreme conditions. By using a self-learning algorithm the current-voltage model adapts itself to the actual conditions within the battery. As a result, both the state of charge and the actual capacity of the batteries can be assessed. The state of charge is therefore based on the actual capacity rather than the nominal capacity of the battery. This leads to a significant improvement in accuracy, especially in situations where the temperature is low, the discharging current is high or the battery is very old. The Sunny Island inverters also reliably notify the plant operator when the temperatures are too low or the batteries are at the end of their service life.

SMA charge regulation

Another positive factor of the Sunny Island inverters is their extremely preserving charge regulation. It automatically selects the optimum charging strategy for the battery type and the situation in which it is used. Thus, overcharging is prevented and the battery is fully charged at regular intervals. The available charging power is also used optimally at all times. Also, as a result the determination of the state of charge is kept largely free of errors over a long period of time. In addition, cell divergence is prevented by regular equalization charge. This is extremely important in ensuring a significantly longer battery service life.

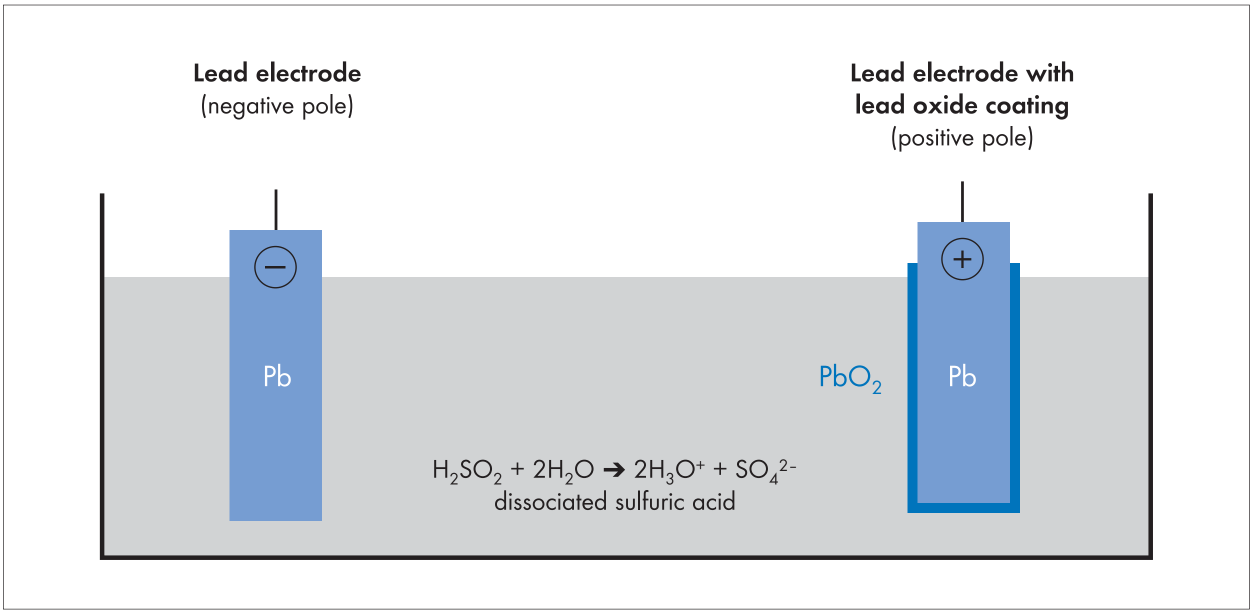
Easy to use

For system designers and plant operators, the SMA state of charge determination provides ease of use: when commissioning the inverters, they must only specify the nominal voltage, the battery type, and the nominal capacity. Then, during operation, the Sunny Island inverters, much like a fuel gauge, constantly provide information on the actual state of charge of the accumulators. As a result the user learns how to operate the system more and more efficiently, and can use it perfectly.

Save twice the costs

Due to the exact determination of state of charge as well as precise charge regulation, overcharging and deep discharge are reliably prevented in Sunny Island systems. Accordingly, the accumulators can be used for longer periods: the battery management system developed by SMA ensures that the battery lifetime stated by the manufacturer can also be achieved in off-grid systems. This is not usually the case with competing devices – these often only realize half of the lifetime stated by the manufacturer. The SMA battery management saves the system operator the necessity of having to make a very early replacement of individual accumulators or the entire battery bank and the respectively greater purchase costs.

Furthermore, accurate state of charge determination enables an optimum exploitation of the battery capacity. This means that smaller and therefore more cost-effective batteries can be used without loss in performance and with a longer service life. The SMA battery management system thus offers the optimum conditions for running stand-alone systems inexpensively, reliably and efficiently.



Principle design of a lead-acid battery

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