



Battery Management in Stand-Alone Systems



SMA inverters impress with precise state of charge determination

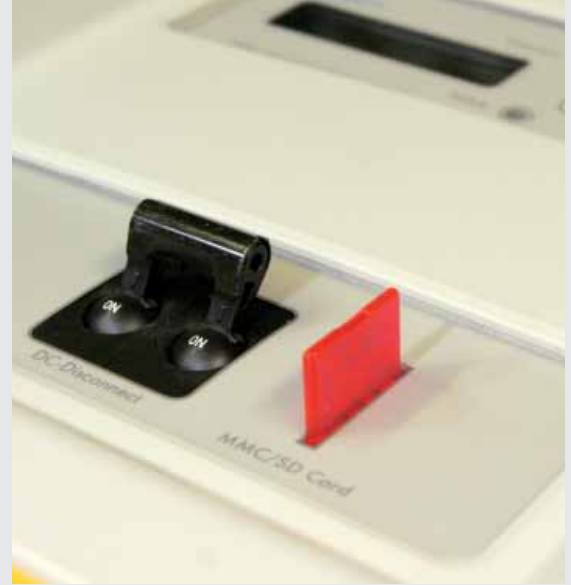
Summary

Stand-alone power supply systems 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 onsite such as electricity from photovoltaic systems, for instance. 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 seen as the most risk-prone component in stand-alone systems. This can largely be attributed to inaccurate battery management. The main problem is that the state of charge of batteries is very difficult to measure. The ability to accurately ascertain the state of charge is a basic requirement for proper operation and thus maximum battery service life. If the battery management system is not working accurately, then system operators are going to have to replace the batteries at a relatively early stage.

With its Sunny Island battery inverters, SMA offers the optimal solution: a special battery management system that is based on the precise assessment of state of charge. By combining the three most common methods of state of charge assessment, these devices achieve a measurement accuracy of over 95 %. Such a high level of accuracy prevents the accumulators from overcharging and deep discharging. This offers clear advantages: In comparison to competitors' devices, the battery management system developed by SMA can almost double the service life of the accumulators. As a result, individual accumulators no longer have to be replaced unnecessarily and the high maintenance costs are reduced. Furthermore, accurate assessment enables optimal exploitation of battery capacity. This means that smaller and thus more cost-effective batteries can be used without loss in performance and with a longer service life.





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 onsite such as, for example, electricity from photovoltaic systems, wind power plants or hydroelectric power plants. Connected to a battery unit, in which the energy is stored until it is actually used, 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 living without electricity today. Sunny Island systems are therefore frequently used in remote regions where access to the public grid is difficult or even 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. This is primarily due to the fact that the state of charge of batteries is difficult to measure, and that the calculated service life is often not reached. For system operators, this means that accumulators, which are already quite expensive, have to be replaced at a relatively early stage (compared to other components). To avoid this, the accumulators used in stand-alone power supplies often have more capacity than is actually needed. This does indeed give the system operator more leeway, although not necessarily a longer accumulator service life. Even though the investment costs increase, the service life of an accumulator lasts still only 10 to 15 years at most, or even less under real-world conditions.

Because this method is also very costly (the price of batteries increases with their size in an almost linear fashion), SMA is constantly working to optimize the process for determining state of charge.

The Accumulator: Stores Energy – Provides Energy



The Conversion of Energy

The accumulator stores energy and supplies it when needed. It does this on the basis of an electro-chemical process: when the accumulator is charging, electrical energy is converted into chemical energy. The accumulator stores this chemical energy. When a load is connected or started, it converts the stored energy back into electrical energy and makes it available for use.

The conversion of electrical energy into chemical energy has two decisive advantages: Firstly, chemical energy has a higher energy density, which means, in comparison, more energy can be stored. Secondly, the losses which occur during the storage period are many times lower with chemical energy storage than with electrical energy storage.

Electricity for on the go, at home or in off-grid areas

Accumulators are used wherever grid-independent operation of electrical devices is necessary or desired. They are used in small utility objects such as 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 which have no access to a public grid.

Capacity & State of Charge Determination

The Capacities of a Battery

The term "capacity" refers to the amount of charge an accumulator can supply when it is fully charged. It is indicated in ampere hours (Ah), and depends on the discharging process, i.e., on the discharging current, the accumulator's final discharge voltage (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 loads.

A distinction is generally made between two capacities: the nominal capacity, which is the capacity of a new battery based on the manufacturer's specifications, and the actual capacity, which is influenced by the age and the temperature.

The State of charge

An accumulator's state of charge or "SOC" for short, provides an indication of the amount of charge that is currently available. The state of charge is indicated as a percentage so that a battery with an SOC of 100 % is fully charged. The battery is empty if the value is 0 %. Note that lead acid accumulators should not drop below a value of 20 - 40 % since otherwise dangerous deep discharging occurs which significantly reduce the service life of the battery or even destroy it outright.

Although a battery's state of charge can refer to the battery's nominal capacity, it must not be confused with the remaining amount of utilizable charge since that depends on many parameters such as the temperature, age and previous use of the accumulator. This is why SMA's indication of the state of charge is based on the actual capacity. It 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. The simplest way in which this can be realized is by limiting the charging voltage. More complex charge controllers use several 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 can be already integrated within the inverter, as is the case with SMA Sunny Islands.



No Battery Lives Forever



Why Determine the State of charge?

The service life of accumulators depends on how they are charged and discharged, and therefore also on a precise assessment of their 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 present state of charge, because in the event of a deep discharge, chemical processes which cause considerable aging occur inside the accumulator.

What Causes a Battery to Age?

1. Sulfation

The normal discharge reaction in a lead acid battery causes lead and lead dioxide to convert to lead sulfate. This process leads to a reduction in

the concentration of sulfuric acid inside 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 cannot be dissolved. Thus, they are not available for the reversible process. This occurrence is referred to as sulfation.

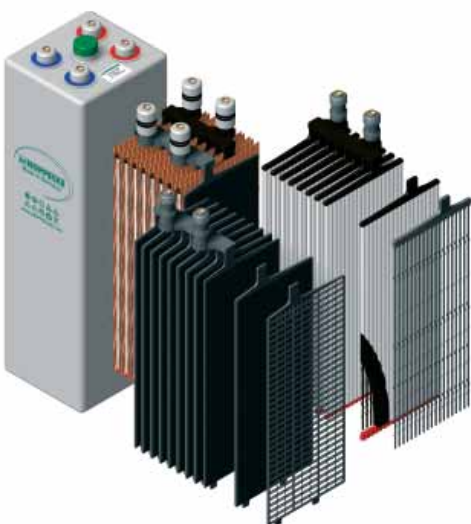
2. Corrosion

During deep discharging or overcharging, the lead grids inside the accumulator react with the sulfuric acid more intensively. Over the long term, this causes grid corrosion: the grid cross-section decreases and thus the grid resistance increases. This causes the conductivity of the accumulator to worsen considerably over the course of time. Deep discharge aids this process, and causes premature aging of the energy storage systems.

3. "Cell Divergence"

No two accumulators are the same, even if they look identical, have the same specified nominal capacity and are discharged in the same manner. When discharging they can behave differently to one another, even if only slightly. Thus, the "weak" cells in a battery's structure reach a state of deep discharge earlier, which means they age faster than other cells due to sulfation 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 sulfation and corrosion. However, this is a phenomenon which even an intelligent battery management system cannot control.



The Lead Acid Accumulator

The lead acid accumulator is the most commonly used accumulator in stand-alone systems. 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. While 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 Assessing the State of Charge



Battery Monitoring by Measuring Voltage

There are several ways to prevent both an overcharging and deep discharging of accumulators. The simplest and most commonly used method is to set a final charge voltage and a final discharge voltage. In this method, during the charging process the voltage is constantly adjusted after the final charge voltage is reached. The discharging process ends once the accumulator reaches the defined threshold. As battery voltage can be measured easily, this method is a very obvious option. However, it is not suitable for protection against deep discharging since the state of charge of the battery types under different loads does not vary in direct relation to the voltage. 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. Note here that the battery may not be charged or discharged for a period of several days. Even in this case the relationship between state of charge and open circuit voltage can vary greatly from battery to battery.

Current-Voltage Models

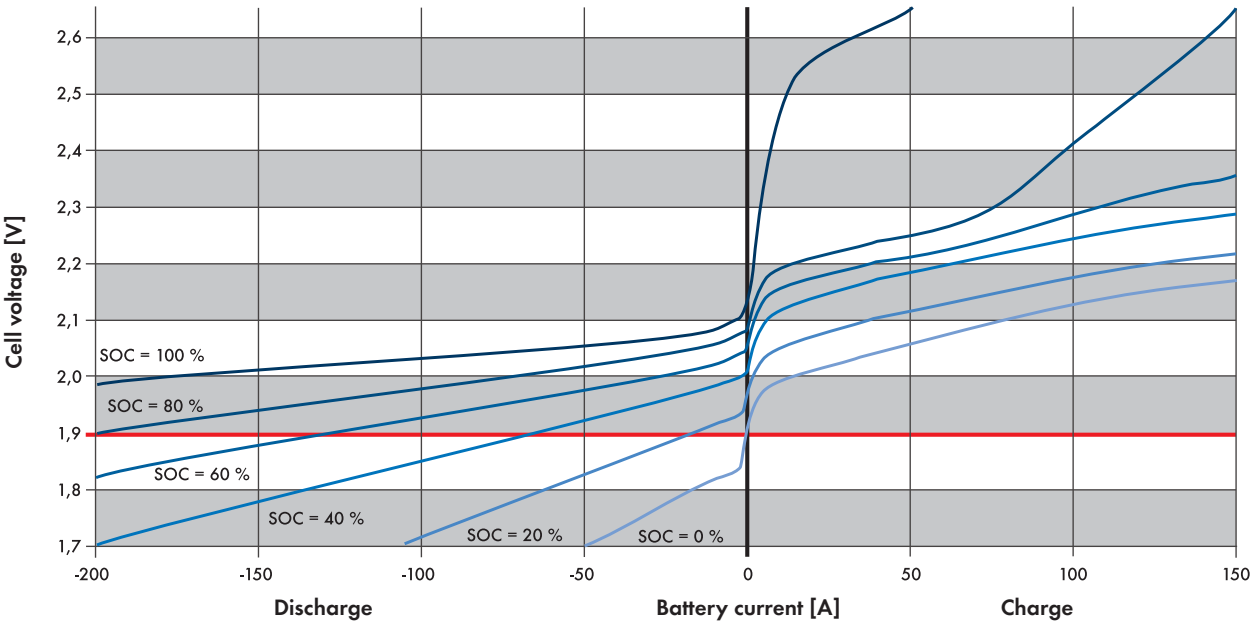
Current-voltage models incorporate both the voltage and the battery currents when calculating the state of charge. Thus, the dependence of battery voltage on charging and discharging currents is taken into account, and it is possible to determine the state of charge somewhat more precisely than when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

Calculating the Charge Balance

A third possible course of action against overcharging and deep discharging is the calculation of the charge balance. This involves measuring the cur-

rent flowing in and out of the accumulators and calculating the balance. A necessary condition for this method is that 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 problems with this method include the non-measurable side reactions in the battery and the required level of accuracy when measuring the current. This accuracy decreases as the of time since the last full charge increases, because the measurement errors are incorporated into the balance equation, regardless of how small they may be. Thus, devices based solely on calculation of the charge balance are not suitable for PV systems, as here it is often 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 the SI 5048

Assessing state of charge at SMA

Precise

The Sunny Island SI 4500 and SI 5048 stand-alone inverters from SMA are able to ascertain the state of charge of "their" accumulators in a very precise manner. To this end, SMA has combined the strengths of all three of the methods shown here. The balance calculation method is in the foreground, i.e., the measurement of the inflowing and outflowing current. As this method would be relatively unreliable by itself, especially for PV systems integrated in stand-alone grids, it is supplemented by a current-voltage model in certain situations. These voltage measurements are performed and added to the balance equation, for example, at night when the outflowing current is low. In this manner, the Sunny Islands achieve measurements with a precision of over 95 %.

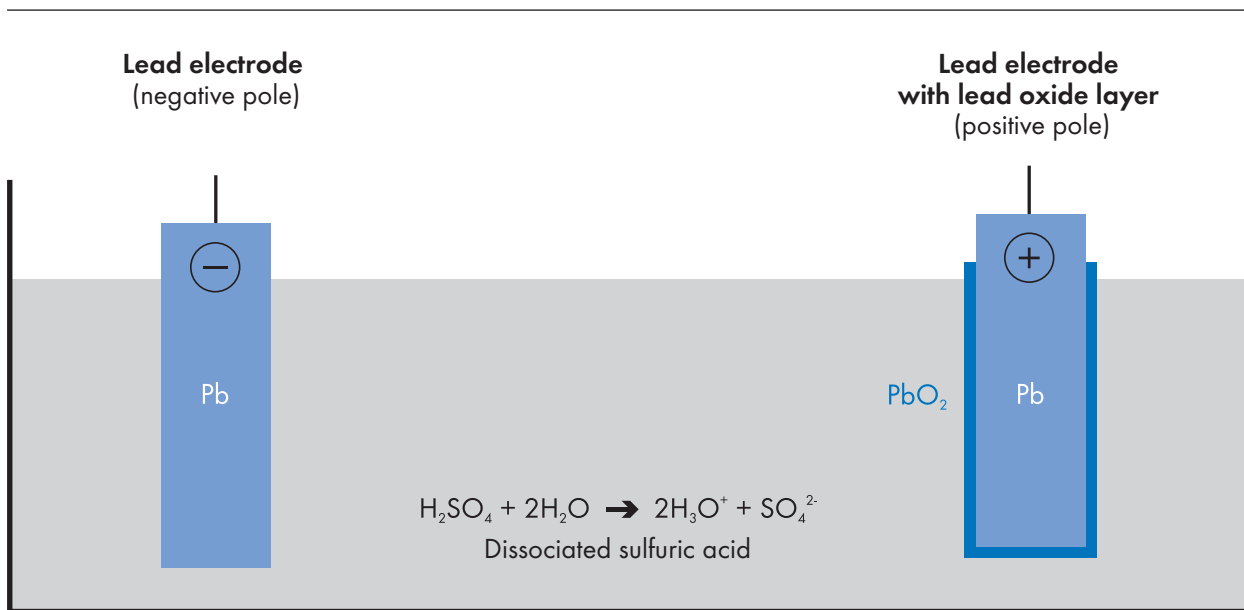
Adaptable

The assessment of the state of charge is automatically adjusted according to battery type, age, and temperature, which enables high precision even under extreme conditions. By using a self-learning algorithm, the current-voltage model is capable of adapting itself to the actual conditions in the battery. As a result, both the state of charge and the actual capacity of the batteries can be estimated. 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 Islands also notify the system operator when the temperatures are too low or the batteries are at the end of their service life.

Charge Control at SMA

Another positive factor of the Sunny Islands is their highly sparing charge control. It automatically selects the best charging strategy based on 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 in an optimal manner at all times. The ascertainment of the state of charge can be kept largely free of errors over a long period of time. In addition, cell divergence is prevented by regular equalization charging. This is extremely important to guarantee a significantly longer battery service life.





General Structure of a Lead Battery

Easy to Use

For system planners and operators SMA's assessment of the state of charge offers a high level of convenience: starting up the inverters is simply a matter of specifying the nominal voltage, the battery type and the nominal capacity. Then, during operation, the Sunny Islands, much like a fuel gauge, constantly provide information on the present state of charge of the accumulators. Thus, the user learns how to handle the system better and better, and to use it perfectly.

Save Twice the Costs

Due to exact assessment of the state of charge, and precise charge control, overcharging and deep discharging are reliably prevented in Sunny Island systems. The accumulators can thus be used for a

correspondingly long period of time: In comparison to competitors' devices, the battery management system developed by SMA can almost double the service life of the accumulators! As a result, system operators no longer need to replace individual accumulators or the entire battery bank at a very early stage and are thus able to lower their purchase costs.

Furthermore, accurate state of charge determination enables an optimal 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 optimal conditions for running stand-alone systems inexpensively, reliably and efficiently.

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