Technical Information

Average Efficiency of the SMA Flexible Storage System

The average efficiency of a system for intermediate storage of energy, e.g. of the SMA Flexible Storage System, indicates how efficient this system performs intermediate storage of energy. Currently, however, there are no standardized requirements as to which measured values under which conditions must be used for calculation of the average efficiency. As this document shows with examples, many influencing factors can affect the result of an efficiency calculation. Without standardized requirements, any calculations for the average efficiency of different systems for intermediate storage of energy can only be compared to a limited extent. For this reason, this document provides an insight into the calculation of efficiency and identifies factors that influence the average efficiency of an SMA Flexible Storage System.

1 Calculating the Average Efficiency

The average efficiency η of the SMA Flexible Storage System is influenced by the following factors:

- Efficiency of the Sunny Island when charging
- Efficiency of the battery
- Efficiency of the Sunny Island when discharging
- Energy losses, e.g. in conductors, fuses and control devices
- Times of no-load operation*

All these factors are automatically taken into account if the energy amount taken by the SMA Flexible Storage System from the household grid, E_{charge}, and the energy amount released into the household grid, $E_{discharge}$, are combined in a ratio.

$$\eta = \frac{E_{discharge}}{E_{charge}}$$

Both energy amounts can be read very easily in Sunny Portal on the page **Energy Balance**, per day, per month and per year. The energy amount E_{charge} is displayed as **Battery charging** and the energy amount $E_{discharge}$ as **Battery discharging**.

There may be days when the battery is charged but, due to low electrical consumption, it is not discharged. At the end of the day, the total amount of charged energy would still be stored intermediately in the battery. If you use the formula above to determine the average efficiency on such a day, the value would approach zero. On the other hand, there are also days on which the battery is discharged but not charged. If the average efficiency was determined on such a day, the value would approach infinity. Therefore, in order to calculate the efficiency, the energy stored intermediately in the battery must be considered in addition to the charging and discharging energy.

* The Sunny Island automatically switches to no-load operation if the battery has been discharged to the lower discharge threshold. This reduces the no-load consumption of the Sunny Island from 27 W to 7 W.

2 State of Charge of the Battery at the Beginning and End of the Measurement

With the SMA Flexible Storage System, it is difficult to obtain measured values in such a way that the states of charge of the battery are the same at both the beginning and end of the measurement. In order to calculate the efficiency of the SMA Flexible Storage System as independently of the beginning and end states of charge of the battery as possible, the measured values for battery charging and discharging should be much greater than the battery capacity. This is the case, for example, if you use aggregate values over the course of a month or, even better, a year. In contrast, the values averaged over the course of a single day, without taking into account the state of charge of the battery, lead to average efficiencies that are almost meaningless.

The state of charge of the battery is thus comparable with the filling level of a fuel tank. If you calculate the fuel consumption of your car by way of the amount of fuel needed to fill the tank, the filling level of the tank must be the same before and after the mileage measurement.

The difference in the states of charge between the start and end time of the calculated efficiency enables you to take the energy that is still stored intermediately into account in the calculation. This is explained in more detail below.

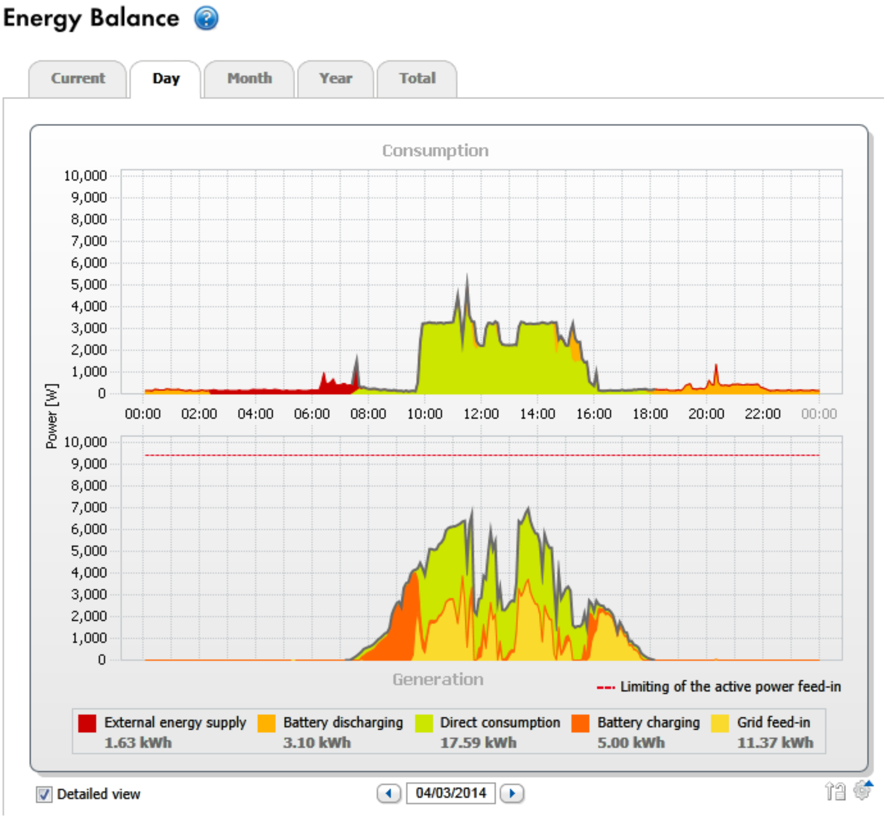

Figure 1: Energy balance of a real SMA Flexible Storage System from March 4, 2014 (example)

2.1 Calculating the Efficiency Without Taking States of Charge into Account

$$\eta = \frac{E_{discharge}}{E_{charge}}$$

On March 4, 2014, the following values were measured related to this day and displayed in Sunny Portal:

- **Battery discharging** = $E_{discharge}$ = 3.10 kWh
- **Battery charging** = E_{charge} = 5.00 kWh

According to the calculation, this results in an average efficiency of η = 62%.

2.2 Calculating the Efficiency Taking the States of Charge into Account

Example:

With reference to the considered SMA Flexible Storage System, the following values were recorded for the state of charge of the battery:

- Total battery capacity: Q = 5.50 kWh
- State of charge of the battery on March 4, 2014 at 0:00 a.m.: SOC_{start} = 38%
- State of charge of the battery on March 4, 2014 at 0:00 p.m.: SOC_{end} = 53%

The state of charge of the battery has risen by 15 percentage points. 15% of the battery capacity of this SMA Flexible Storage System with 5.50 kWh corresponds to energy E_{delta} of 0.83 kWh.

If the efficiency is calculated without taking the states of charge into account, the energy E_{delta} is included in the calculation as energy losses. However, the energy E_{delta} is not lost but stored intermediately. The energy E_{delta} can be discharged the next day with the efficiency of the Sunny Island. If the energy amount $E_{discharge}$ is combined with the energy amount E_{delta}, the formula above results in an efficiency of η = 78%.

In the example considered here, taking the start and end states of charge of the battery into account means that the result of the calculation is 16 percentage points higher than when the states of charge are not considered. Instead of an efficiency of η = 62%, the result is an efficiency of η = 78%.

3 Inaccuracies During Recording of Measured Values

The results of the calculation of the average efficiency are only as accurate as the measured values on which the calculation is based. The measured values for **Battery charging** and **Battery discharging** are measured on the AC side of the Sunny Island. The sensors have been optimized for operation of the Sunny Island and not for precise recording of energy amounts. In a car, the average efficiency calculated from the measured values for **Battery charging** and **Battery discharging** corresponds to the fuel consumption indication. The fuel consumption indication in the car is based on the measured values of sensors that have not been optimized for the precise measurement of fuel consumption. As a result, there are deviations from the real values, similar to the deviations of the calculated average efficiency from the real average efficiency of the SMA Flexible Storage System.

The input current range of the Sunny Island 6.0H / 8.0H is ±120 A. With a measurement accuracy of ±1%, this results in a measurement error of up to 270 W at 230 V_{AC}. Device-internal measures reduce this measurement error to 10 W to 20 W in the long-term average. Within a year, however, the measurement errors can total 90 kWh to 180 kWh.

Example:

Within a year, the following values are displayed in Sunny Portal for an SMA Flexible Storage System:

- **Battery discharging** = $E_{discharge}$ = 1,190 kWh
- **Battery charging** = E_{charge} = 1,700 kWh

This results in an average efficiency of η = 70%.

The measurement error of battery discharging is 90 kWh and the battery discharging is actually $E_{discharge}$ = 1,280 kWh. With 1,280 kWh, this results in an efficiency of η = 75%. In the example, the actual efficiency value is five percentage points higher than the efficiency calculated from the measured values of Sunny Portal.

For this reason, when interpreting the average efficiency, the relatively high deviation from the actual efficiency must be taken into account. We can typically assume an error of ±5% here, which in special cases, can amount to ±10%.

4 Key Factors Influencing the Real Efficiency

The real efficiency of a system for intermediate storage of energy depends on the design of the system and how it is operated. With the SMA Flexible Storage System, the following factors in particular affect the efficiency of energy transformations and, therefore, the average efficiency:

- Annual energy requirement
- Distribution of power drawn from the utility grid throughout the day and the year
- Installed PV power
- Position and alignment of the PV system
- Type and storage capacity of the connected battery

The SMA Flexible Storage System is very well suited for an annual energy requirement of 3,000 kWh to 7,000 kWh and for PV systems in Germany with 3 kWp to 10 kWp of installed PV power and batteries of 3 kWh to 10 kWh.

The SMA Flexible Storage System operates optimally with an annual energy requirement of 5,000 kWh, a PV generation of 5,000 kWh and a usable battery capacity of 5 kWh or higher. The principle correlations are illustrated by the following three examples. These apply in each case only for the framework conditions defined below the diagram.

Example 1: Average efficiency dependent on annual energy requirement

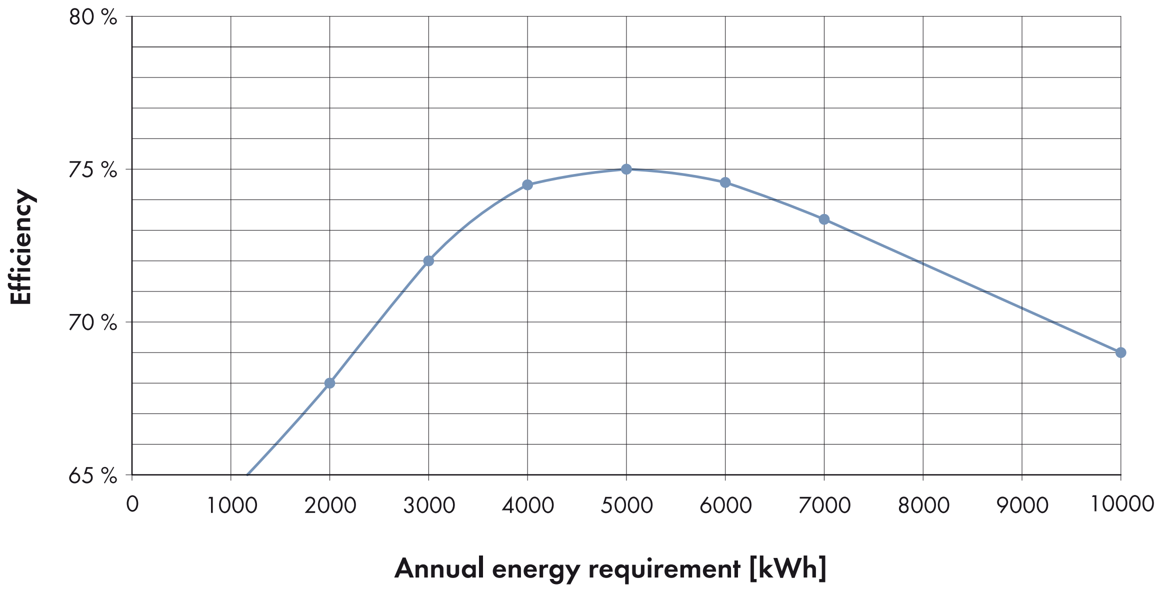

Figure 2: Average efficiency of an SMA Flexible Storage System with a Sunny Island 6.0H, a lead-acid battery with a usable battery capacity of 5 kWh and a PV generation of 5,000 kWh per year

The annual energy requirement affects especially the behavior of the SMA Flexible Storage System when discharging. The figure shows that the efficiency is significantly reduced with a very low annual energy requirement of under 3,000 kWh per year and is also lower with a very high annual energy requirement. This is partly due to the Sunny Island, which has an optimum efficiency at approximately 30% of nominal power and an optimum operating range between 10% and 50% of nominal power. If the Sunny Island is operated very frequently outside this operating range with a very low energy requirement, the average efficiency drops significantly. The same applies with a very high energy requirement. However, in this case, another effect occurs. The battery efficiency is also very much dependent on the charging and discharging power. The pure battery losses increase quadratically with the charging and discharging current. If the battery is always discharged with relatively high currents, the average battery efficiency decreases. Example 1 shows how the average efficiency decreases in case of a very high annual energy requirement.

Example 2: Average efficiency dependent on PV generation

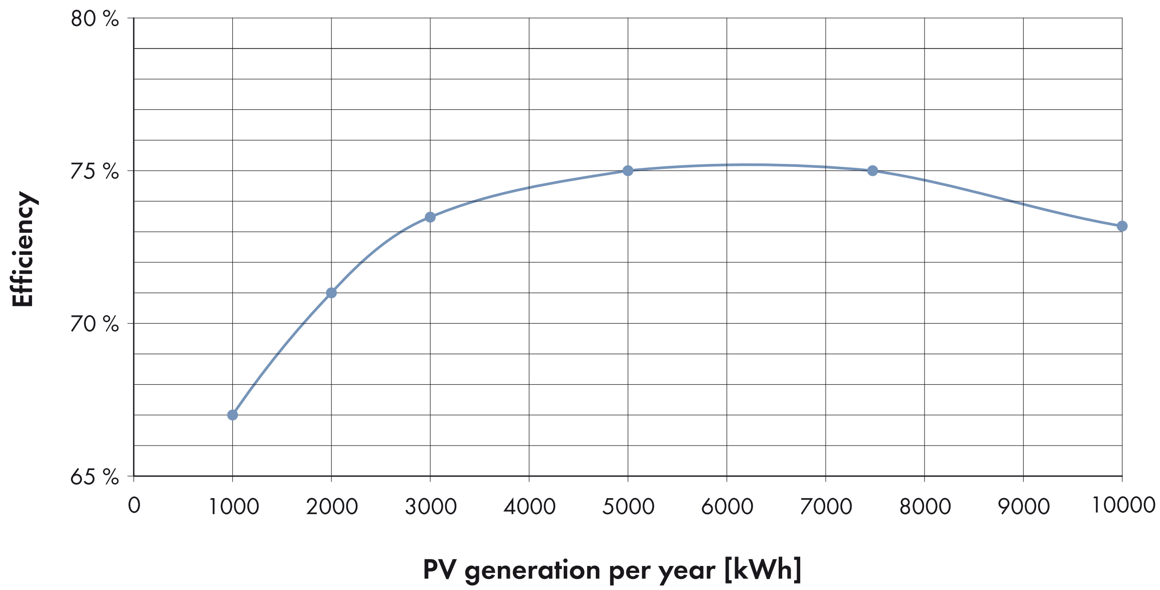

Figure 3: Average efficiency of an SMA Flexible Storage System with a Sunny Island 6.0H, a lead-acid battery with a usable battery capacity of 5 kWh and an annual energy requirement of 5,000 kWh

The pattern of the average efficiency over the PV generation is very similar to that of the average efficiency over the annual energy requirement. The same principles apply here, with the difference being that the PV generation determines the charging behavior of the SMA Flexible Storage System. Where PV generation is very low, the standby power losses are proportionally very high and result in the average efficiency of the SMA Flexible Storage System being low. Where PV generation is very high, the charging current is very high. In this case, the Sunny Island no longer operates with optimum average efficiency, and the average efficiency of the battery is also lower.

Example 3: Average efficiency dependent on usable battery capacity (lead-acid battery)

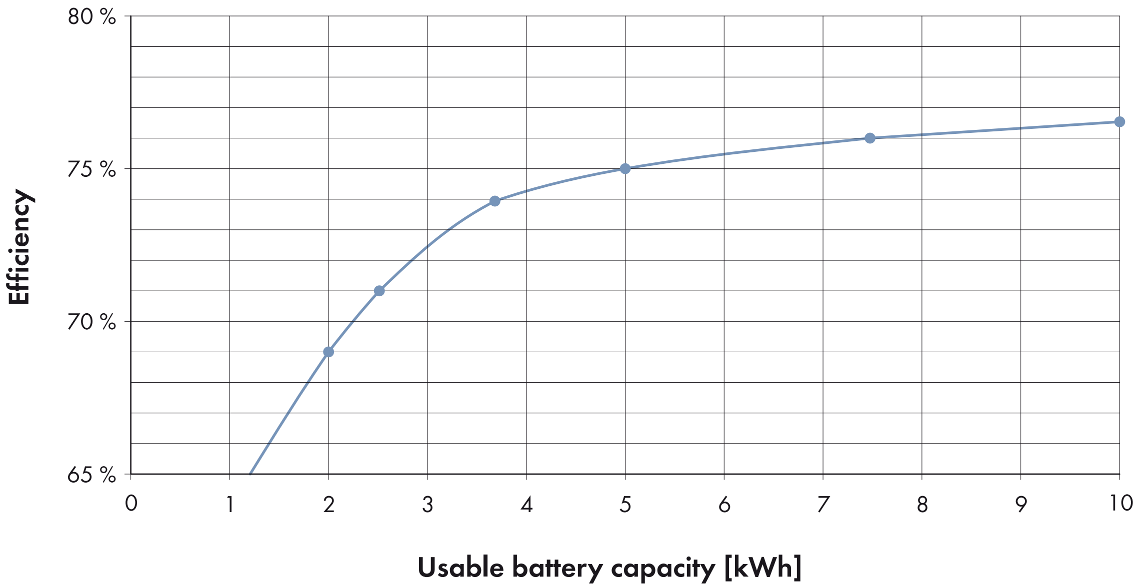

Figure 4: Average efficiency of an SMA Flexible Storage System with a Sunny Island 6.0H, an annual energy requirement of 5,000 kWh and a PV generation of 5,000 kWh per year

The usable battery capacity has the clearest influence on the average efficiency of the SMA Flexible Storage System. The internal resistance of a battery decreases on a linear basis with increasing battery capacity. In contrast, the losses increase quadratically with the power upon charging and discharging. In concrete terms, this means that with a battery capacity of 2.5 kWh instead of 5 kWh, the losses in the battery increase fourfold. With lithium-ion batteries, this effect is less significant since these batteries naturally have a significantly lower internal resistance.

The examples show that the real average efficiency of the SMA Flexible Storage System with lead-acid batteries is between 65% and 77%. If two or three of the effects illustrated above occur together, e.g. an annual energy requirement of less than 2,000 kWh, PV generation of less than 2,000 kWh and/or a battery capacity of less than 2 kWh, average efficiencies of 60% are also possible. This correlation can be observed in winter in almost all systems for the intermediate storage of energy. Due to the very low PV yield from November to January, the efficiency in these months is frequently between 50% and 60% and, with increasing use, this increases during the spring and summer months. This is due to the fact that the system for intermediate storage of energy always requires a certain amount of energy for its own operation, whether this is currently being used or not.

Frequent use of the intermediate storage of energy with a correspondingly high nominal energy throughput generally improves the efficiency of the entire SMA Flexible Storage System. Similar to a car engine idling, the SMA Flexible Storage System consumes electrical energy independently of whether or how this energy is used. If the battery is frequently charged and discharged, the standby power losses of the Sunny Island and the self discharge of the battery are relatively minor compared to the total nominal energy throughput. The less energy that is stored intermediately in the battery, the more the efficiency of the SMA Flexible Storage System decreases.

The standby power losses and the self discharge of the battery have an ever greater effect. In order to minimize the losses on days with very low usage of the battery, the Sunny Island switches to energy-saving mode. This is comparable to the automatic start-stop function in cars. This way, for example, the Sunny Island 6.0H reduces its consumption in no-load operation from 27 W to 7 W.

The Sunny Island cannot influence the losses that occur through the self discharge of the battery. In the case of lead-acid batteries, these are only in the range of 3% to 5% per month and therefore hardly relevant.

With lithium-ion batteries, the battery management integrated in the battery draws additional energy from the battery. The typical consumption of 5 W and 15 W is relevant here and causes losses of 40 kWh to 130 kWh over the year. The details on self discharge and the efficiency of lithium-ion batteries do not normally take these losses into account. These losses of up to 130 kWh per year can lead to a situation where the efficiency of lithium-ion batteries, which is actually 8% to 10% better, is required in its entirety for the battery management. In extreme cases, the average system efficiency with a lithium-ion battery can even be lower than that with a lead-acid battery. When selecting a lithium-ion battery, care should be taken to ensure that the battery management has a low power consumption
(see the documentation of the battery manufacturer).

5 Summary

The average efficiency of an SMA Flexible Storage System depends clearly on the design and operation of the system. For this reason, the average efficiency of the battery can deviate from the typical efficiency of 75% in the case of lead-acid batteries and 84% in the case of lithium-ion batteries, e.g. if very little energy can be stored intermediately in the storage system. This case occurs mostly during the winter months but can also be caused by the system design. With a very low annual energy consumption, a very low PV generation or a very low battery capacity, the system too rarely attains the optimum operating point. In such cases, the average efficiency of lead-acid batteries can range from 60% to 65%.
For lithium-ion batteries, the average efficiency also depends on the energy consumption of battery management.
With electrical consumption of more than 10 W and low nominal energy throughput through the battery, the lithium-ion battery is less efficient than a lead-acid battery with the same usable battery capacity.

Calculation of the average system efficiency using the energy values displayed in Sunny Portal for **Battery charging** and **Battery discharging** is very easy. However, with values calculated in this way, the energy stored intermediately in the battery must always be taken into account or a large enough time period must be selected so that the error caused by the energy stored intermediately in the battery is not too large. Also, the measurement inaccuracies must also be taken into account when assessing these values. Errors of ±5% are typical here and, in extreme cases, can reach 10%.