SIEMENS

Totally Integrated Power

Technical Series, Edition 8

SIESTORAGE Energy Storage System – a Technology for the Transformation of Energy System

Answers for infrastructure and cities.

Introduction: transformation of energy system

Sustainable energy supply requires the use of regenerative sources of energy. The speed that is used to push the change from the fossil and nuclear power sources towards wind, solar and bioenergy differs in every country of this planet. Germany has established new boundary conditions for energy supply as a whole through its politically initiated transformation of the energy system and by phasing out nuclear power. In this context it becomes increasingly evident that energy storage systems will be a core element for implementing the transformation of the energy system.

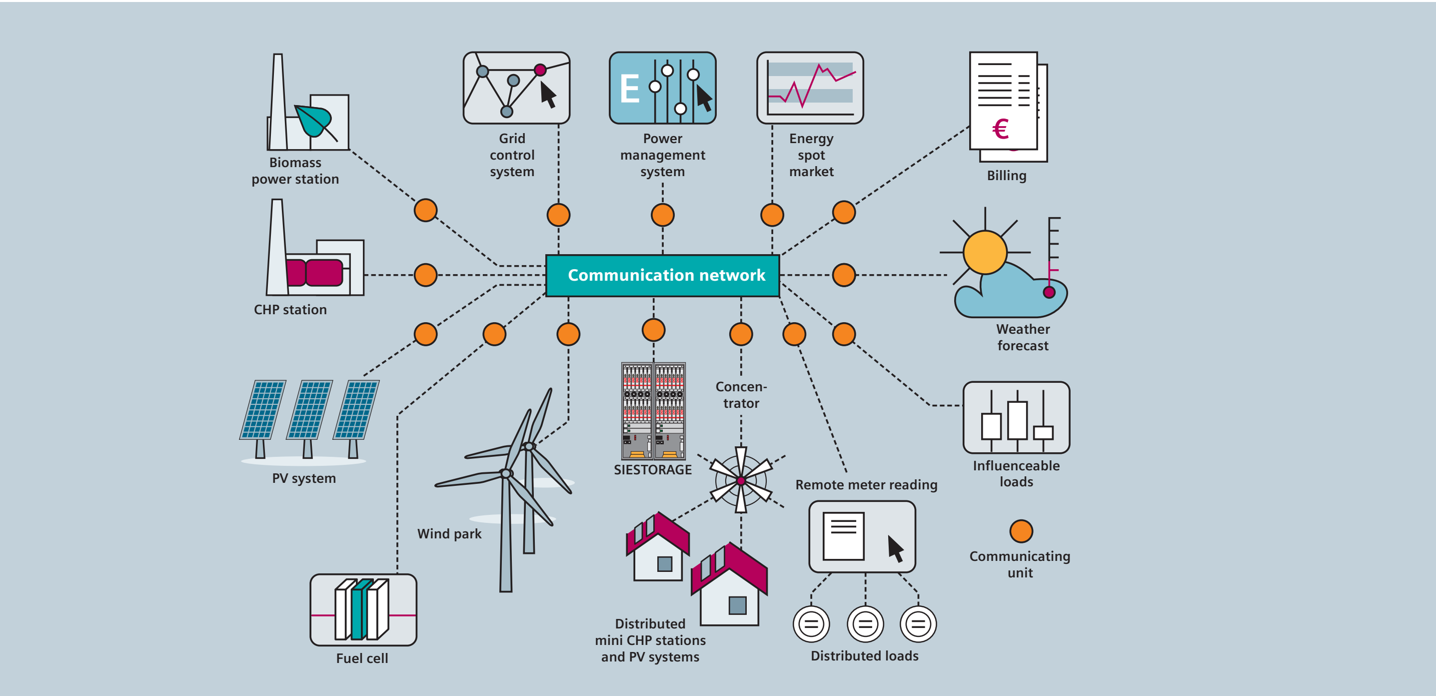
Energy storage systems on the basis of lithium-ion accumulators like SIESTORAGE (Siemens Energy Storage) contribute to meeting the challenge of distribution grids and establishing a balance between the generation and consumption of electricity. Important characteristics of the supply grid which are positively influenced by energy storage systems are:

- Increased power quality
- Integration of distributed renewable energy sources into the grid
- Deployment of control energy reserves
- Improved voltage and supply quality
- Flexibility in peak load management

Another field of application for energy storage systems is the emergency power supply of sensitive industrial production processes, data centres and hospitals. Furthermore, there are energy storage solutions for energy-efficient buildings, isolated networks and smaller independent grids for in-plant demand, for public transport and for electro-mobility applications.

Electricity has the physical property that it must be generated precisely when it needs to be consumed. Kindled by the expansion of power generation using fluctuating regenerative energy sources, the first consequences for the supply grid and the electricity prices come to be felt in Germany. Maintaining the balance between large-scale power stations and distributed power generating systems such as combined heat and power stations (CHP), wind parks and photovoltaic systems has become increasingly difficult. Heat-controlled (CHP) and weather-dependent (solar and wind) power generators require fast control, which possibly cannot be handled by large-scale power stations alone any more. Alternatively, energy storage systems as part of the Smart Grid could be used to keep the balance.

Fig. 1: Integration of SIESTORAGE into a Smart Grid



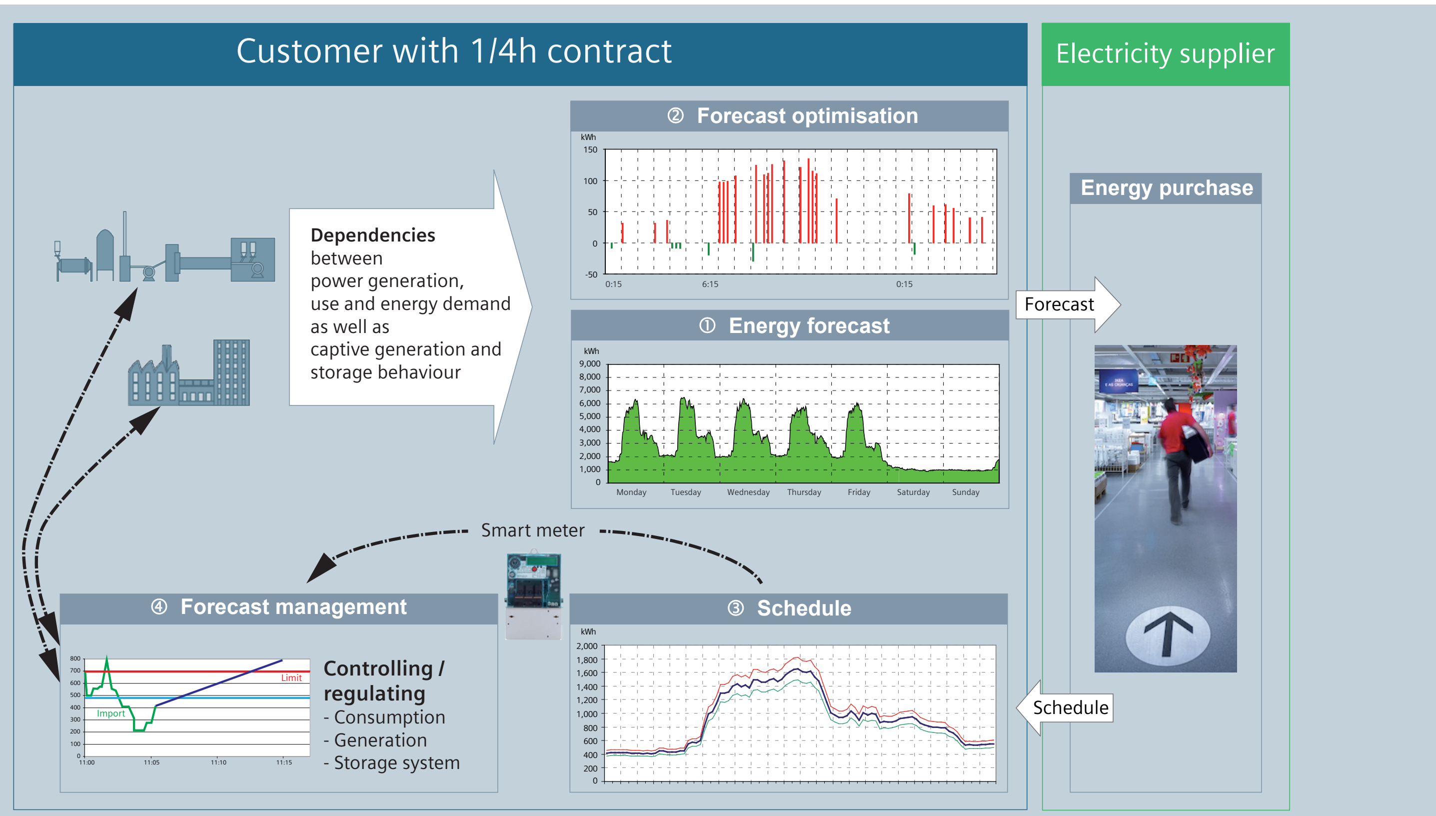
Load variations

It is imperative that power generation follows such load variations. If this is not the case, deviations from normal voltage are the consequence. The permissible voltage deviation as part of the power quality is specified in the EN 50160 standard. Observance of this standard is up to the grid operators. They must ensure that 95% of the 10-minute means of the r.m.s. supply voltage value for every weekly interval are within the range of Un ± 10% under normal operating conditions without failures or supply interruptions. As a result of the liberalisation of the energy market, the roles of grid operators, electricity suppliers and power generators are now separated by jurisdiction as well as by business administration, which aggravates task compliance. Owing to the legal framework, more and more distributed power generators are being integrated into the grids. To let renewables play a more prominent part, the obligation to purchase such energy quantities was introduced for grid operators on the one hand, and power generation for one's own use was subsidized on the other.

But at the same time, the grid operators bear the risk for the consequences of load variations on the electricity grid. Therefore, grid operators draw up forecasts, for example for large-scale consumers and summarized even for entire cities. Besides such already common forecasts, the forecastability of renewable energy feed-in is playing an increasingly important role. But with every prognosis, grid operators run the risk of misinterpretation between forecast and actual consumption.

If the customer takes over the risk of such fluctuations, this will become noticeable in better pricing. This energy demand forecast, known as schedule clause in ¼-h electricity supply contracts, is gaining more and more importance in this context. The customer submits to his distribution grid operator (DGO) a forecast of his energy demand in advance (EU-wide always on Thursdays) in which optimisations at 24-h notice are permitted. The procurement of these forecast energy quantities is up to the electricity supplier. Depending on what was contractually agreed, the customer is permitted deviations in the range of ± 5% or ± 10%, for example. So far, forecasts are optional for the customer and result in more favourable price conditions. But in the long run, they will become mandatory with Smart Grids paving their way.

Fig. 2: Creating transparency of the energy flow



Energy storage and photovoltaic power generation in the energy forecast

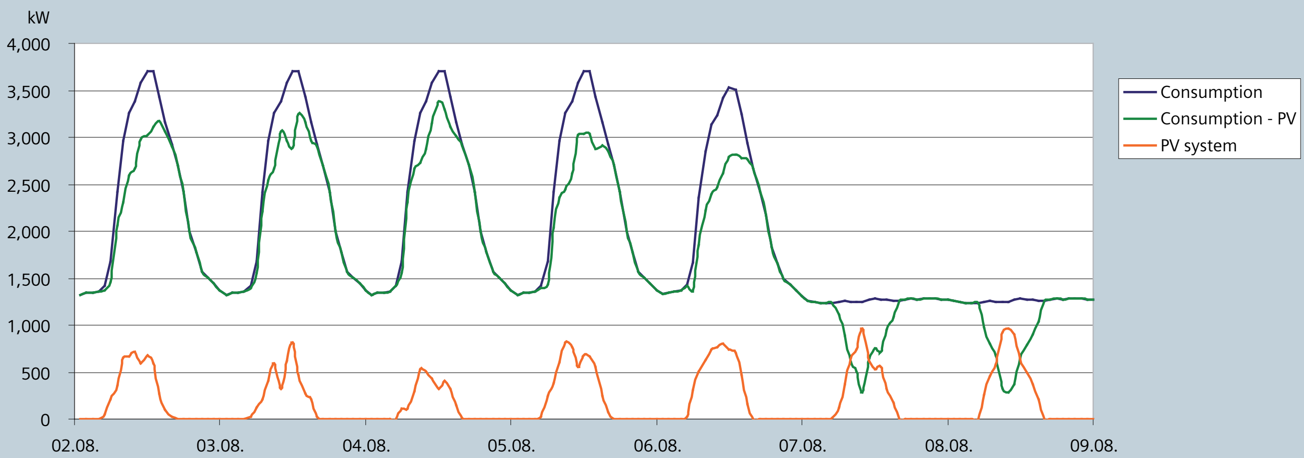
The interplay of power generation on the one hand, and building use and associated energy demand on the other is essential for a well-founded forecast. In addition to this, distributed power generation using renewables will have to be increasingly factored in. Besides the direct connection of power generated from renewable energies to the distribution grid, it may be necessary to integrate such capacities into a holistic power supply concept for the purpose of captive consumption of the power produced in such a way. Here, the risk of weather dependency lies with the customer. In the following, we will discuss the integration of photovoltaic systems into a customer-side power management system.

Today, service providers already offer solar capacity forecasts on the Internet, e.g. see Enercast (http://www.enercast.de). This online service provides a capacity forecast timed to the nearest hour of up to 72 hours in advance. The forecast is based on the weather forecasts of several European weather services. Thus it becomes interesting to combine the analysis of the forecastability of power consumption and photovoltaic power generation with the additional use of a storage system.

The ideal curve of solar power generation – unimpaired from clouds on a sunny day – is bow-shaped, beginning at sunrise, with a maximum around noon and ending at sunset. In reality, however, there will be clouds passing, which creates sags in this curve (see orange curve in Fig. 3). Consumption (blue curve in Fig. 3) is assumed to be continuous and thus well forecastable. However, the difference from consumption and PV generation (green curve in Fig. 3) varies substantially owing to the fluctuations of sun radiation and is thus badly forecastable.

Without a forecast of the PV power for internal, captive consumption, a summated forecast is almost impossible. If the currently generated PV capacity exceeds captive consumption, it is automatically fed into the public grid. But this is not necessarily tolerated by grid operators.

Fig. 3: PV system for captive consumption



The profitability of a PV system with a share of captively consumed solar electricity will rise in the future. Therefore, the goal of a combined PV and energy storage system will be to completely consume the self-generated power and simultaneously achieve a good forecastability of the power drawn from the distribution grid operator (Fig. 4).

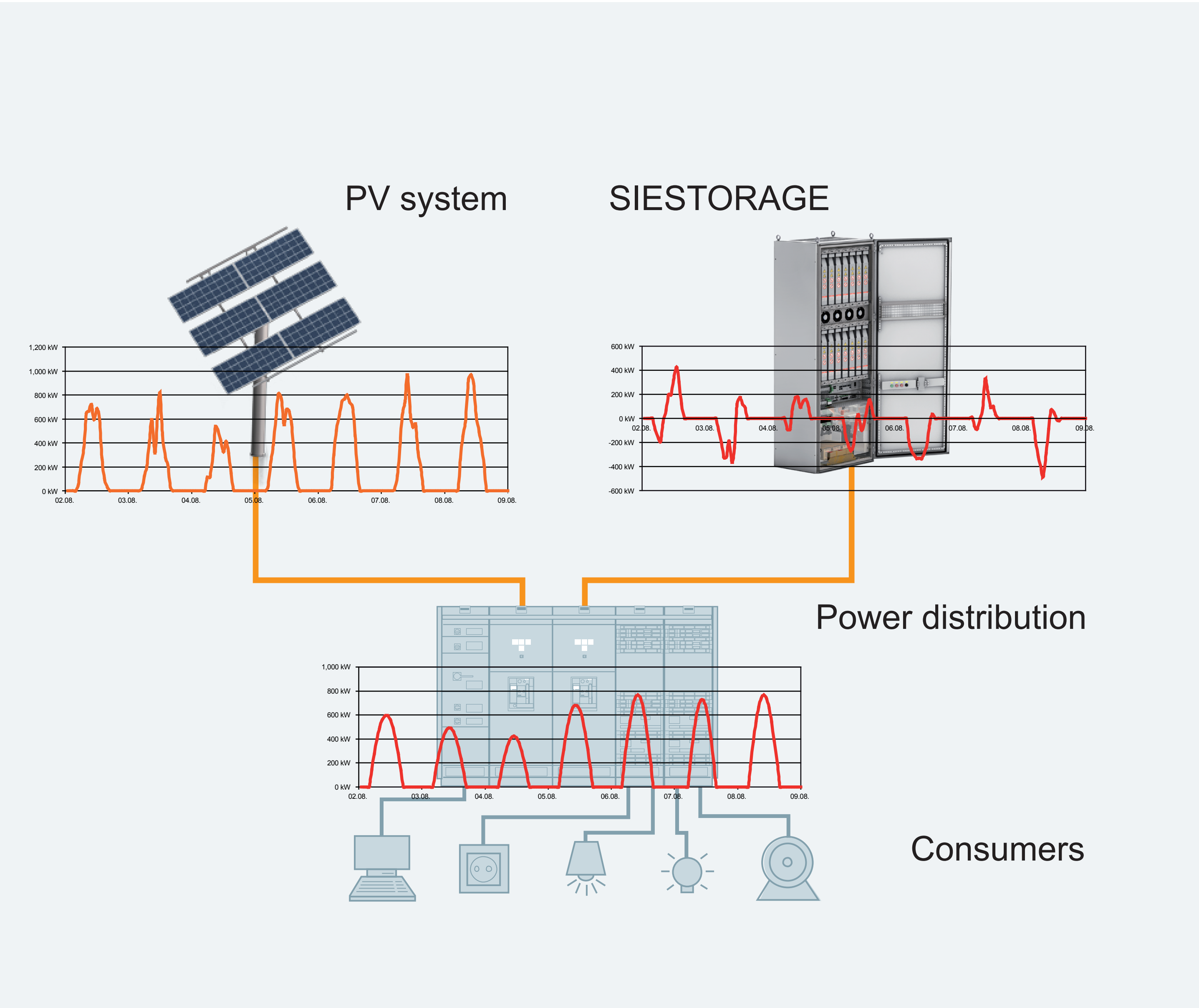
Two vital factors which are to be observed when planning a combined system are the size relations between power generation and storage plus the so-called C-rate for the charging/discharging characteristic of the storage system. The C-rate is defined as the quotient from the current and capacity of an accumulator.

C-rate = current / charge = 1 / time
(output / accumulator capacity in h^{-1})

Example:

When a storage system is discharged at a capacity of 400 Ah, a C-rate of 2 C means that a current of 800 A can be output. Vice versa, with a C-rate of 6 C, a continuous charging current of about 2,400 A can be assumed for recharging. To establish the charging duration, a charge efficiency (also called charge rate) must be considered which has to integrate the charge-current-dependent heat developed during the charging process.

Fig. 4: Power supply concept integrating photovoltaics and a SIESTORAGE energy storage system



Scenarios for PV and storage combinations

In our example, we assume a sunny load curve for power deployment by a PV system with a peak capacity of 1,000 kWp as shown in Fig. 5. The evaluated scenarios start from defined feed-in curves for captive consumption in the user grid:

1. Continuous feed-in of 400 kW over 24 hours every day
2. Continuous feed-in of 400 kW over a limited period of 13 hours (from 6 a.m. until 7 p.m.)
3. Feed-in according to an ideal PV curve (peak at 700 kW), which is assumed to be identical for every day
4. Feed-in with an ideal PV curve whose output peak is adapted to the daily forecast noon peak for solar radiation

The difference between power generation from the PV system and the feed-in curve of respective scenario defines the sizing of the SIESTORAGE energy storage system. We expect that the storage system is completely discharged at the beginning of the assessment period (storage content 0 kWh).

For the evaluation, the difference quantities between power generation and hourly mean feed-in are formed. A positive difference means that the storage system is being charged during the hour under assessment, whereas it is discharged in case of a negative result. The differences are recorded over a week for each scenario and evaluated. The required storage capacity of the SIESTORAGE results from the difference between the maximum and minimum value of this weekly curve in each case.

There are different approaches how to run this combination. Two aspects to be drawn into consideration are firstly, an affordable storage size and secondly, realistic C-rates.

If a product version with a capacity of 500 kWh is chosen for a modular concept of the SIESTORAGE electricity storage system, a nominal output of 2 MW and a peak output of 3 MW will be attained. This means the C-rate is 4 C, if peak output is demanded, it briefly rises to 6 C.

Scenario 1: Continuous feed-in over 24 hours

The mode of operation described in this scenario shall result in a minimisation of the base load. The base load demand of consumers is assumed to be 400 kW, whereby the PV system will have a 2.5-fold peak capacity. As the curve comparison for feed-in and PV output demonstrates (Fig. 5, top), this scenario can hardly correspond to realistic operation if the storage system is to be charged from the PV system alone. Since it is not a matter of the presented assessments to question whether a complementary charging of the storage system from the public grid makes sense or not, we will not go further into this.

The storage curve already makes clear (Fig. 5, bottom) that firstly, a fairly big storage demand is created in scenario 1 (more than approx. 33 MWh) and secondly, that energy would be required from the supply grid very frequently in order to charge the storage system. Otherwise the storage system would be discharged more and more week after week.

Considering the deterioration of PV yield when it is cloudy and owing to a seasonal weakening of solar radiation, we would have to assume much worse boundary conditions for this scenario.

Fig. 5: Temporal course of PV output and feed-in power (top) and storage capacity (bottom) in scenario 1

Scenario 2:
Continuous feed-in over a limited period of time (between 6 a.m. and 7 p.m.)

In this scenario – as in scenario 1 – we do not attach much importance to the aspect whether the energy yield of the PV system suffices to balance power feed-in analysed over one week. The period is selected in order to enable coverage of the base load demand during this period in line with average office hours (Fig. 6, top). A reduction of power output could help to attain a more balanced energy management for the storage system. However, this would not make much difference to the dimension of the required storage capacity. Here too, weather-dependent and seasonal deteriorations would result in a significant increase of the required storage capacity.

Although only ca. 46% less energy is fed in compared to scenario 1, the required storage capacity of 6 MWh is reduced to about 20% of the value for continuous operation (Fig. 6, bottom). Starting from a standard container with a storage capacity of 500 kWh, nine containers would be required to cover the demand. This would mean a very high amount of investment.

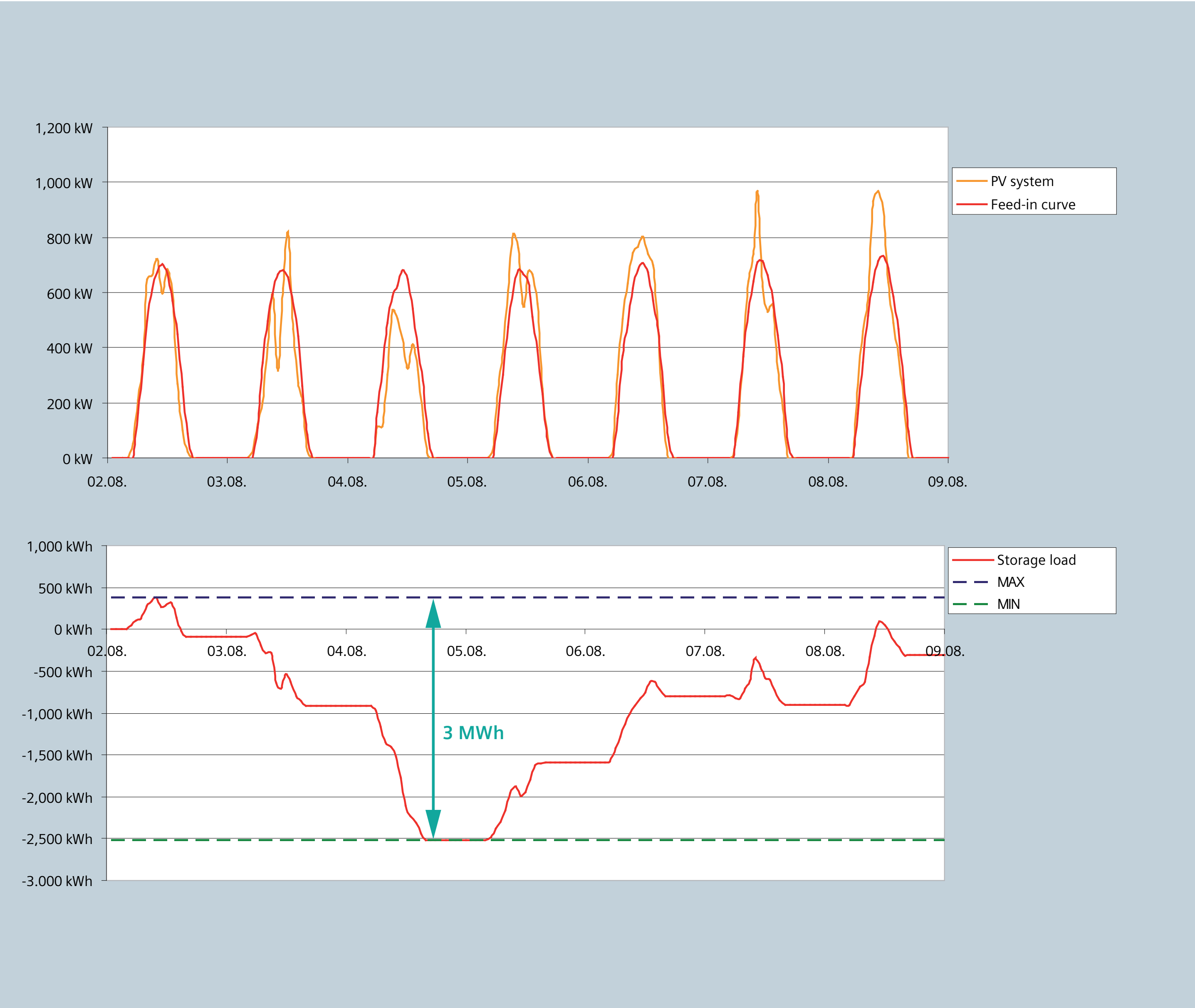
Fig. 6: Temporal course of PV output and feed-in power (top) and storage capacity (bottom) in scenario 2

Scenario 3:
Feed-in with adjustment according to an ideal PV curve

In order to attain a better adjustment of feed-in to the power generated by the PV system, scenario 3 is based on the idea of base load balancing. We now assume an idealized PV performance curve with a peak at 700 kW which is identical for every day.

The storage system is only used to balance deviations from the ideal curve shape to actual PV performance in the scenario (Fig. 7 top). Owing to the curve adjustment, it is only the peaks and sags of PV power output that will particularly strain the charging and discharging process. Apparently, there were more clouds than usual on the third day of the selected week. The great discrepancy between PV output and feed-in on that day (Fig. 7 bottom) therefore determines the storage capacity, which amounts to half the value, i.e. 3 MWh, given in scenario 2. Nevertheless, the six containers required for implementing such a storage capacity are too expensive an investment considering the power versus energy conditions analysed.

Fig. 7: Temporal course of PV output and feed-in power (top) and storage capacity (bottom) in scenario 4



Scenario 4: Adjustment of an ideal PV curve with a day-specifically forecast noon peak

In order to further reduce deviations between the PV output and feed-in power curves, this scenario assumes that there are day forecasts for solar radiation. The forecast energy quantity is set equal to the energy quantity resulting from the given PV output curve for the day. The peak value for the feed-in curve is then calculated day-specifically in such a way that it yields the forecast energy quantity together with the ideal PV curve shape (which is equal to the energy quantity from the PV output curve for the individual day).

Though the peak of the ideal PV curve varies in amplitude (Fig. 8 top), the energy balance at midnight is always equalized (Fig. 8 bottom).

In this case, the storage capacity needed amounts to about 900 kWh, so that two standard storage containers with a total capacity of 1 MWh will be sufficient. The maximum charging power per hour which will be fed into the storage container from the PV system is 350 kW, and the maximum power drawn is 200 kW. Hence a C-rate of 3 C is sufficient. In this scenario, the investment required is within acceptable limits so that a business assessment could be worthwhile.

Fig. 8: Temporal course of PV output and feed-in power (top) and storage capacity (bottom) in scenario 4

Conclusion

It is indispensable for selecting a suitable energy storage system to specify its precise field of application and the boundary conditions prevailing. Only scenario 4 with the best adjustment of the feed-in curve – and hence with a best possible congruence with the PV output curve – calls for a closer examination. In case a PV system is connected as the power source, an annual cycle showing weather and seasonal dependencies as well as the forecastability of these dependencies must be looked into. Today, high-precision regional forecasts for wind and sun are already available for three days in advance. A regulating function of the SIESTORAGE must implement a charging/discharging behaviour according to a forecast curve.

Furthermore, when assuming fluctuating power sources, a statistical limit needs to be set for the availability of the storage system, since there might be imponderabilities. This limit is defined in the planning process for the storage system. It is dependent on the specific application and goes into the planning as boundary condition. A load curve for the application was not yet factored in. And a possible supply target, such as a daily peak load reduction or the specification of a very precise energy schedule, was not yet included into these considerations either. Therefore, further assessments of the efficiency of the SIESTORAGE use are required.

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