Photovoltaic power can be used even when the sun is not shining with the help of a battery system that provides intermediate storage. The result is that electricity not consumed during the day can be used to light the house in the evening. Alternatively, an energy company can draw on this power when demand is high.

For owners of photovoltaic systems, the option of consuming the power they generate themselves has become more attractive since the remuneration for self-generated solar power was revised as of 1 July 2010. PV systems with smart inverters and batteries can help to increase consumption of self-generated power and to ensure a secure power supply for the generating party. In addition, these systems are developing to become an important component of so-called smart grids: They can be used to make energy available when it is in demand and to control and ease the load on electricity grids.

As part of its “Optimisation of Energy Supply Systems” support initiative, the German Federal Ministry for the Environment is promoting research and development work on uninterruptible power supply (UPS) devices and equipment for intermediate storage and the use of PV power by the generators themselves. The first solutions are already available, and research is continuing on cost-effective storage technologies with long service lives.

The use of self-generated solar power can be significantly increased using new combined systems; developers consider it possible that the self-generation percentage could be increased to over 70%. This would also result in reduced loads on electricity grids, particularly in the low-voltage range.

The new combinations of inverters and energy storage devices mark the end of the conventional unidirectional feed-in of solar power: The new decentralised switching unit controls energy flows and decides whether electrical energy will be delivered, stored, used by the generator or else drawn down from the grid.

In the case of a power grid outage, these new combined systems quickly disconnect themselves from the grid. Thanks to the integrated UPS, the most important consumers in the building can remain online in stand-alone operating mode and form a stand-alone grid supported by solar power and batteries. Sensitive systems can continue to be operated using smaller integrated storage devices (2-5 kWh). However, energy-intensive devices such as an electric cooker or a washing machine may represent too much of a challenge for this approach.

Multi-functional inverters and storage equipment for solar power

- Stand-alone operation possible during grid outages
- Increase the consumption of self-generated solar power
- System viability dependent on battery costs
- New PV systems can cap peak loads and contribute to energy management

Using self-generated solar power at night too!
Developers are aiming to significantly increase the use of self-generated solar power and to improve supply security – particularly in areas with fluctuating grid quality – by employing new combinations of “smart” inverters and storage systems. This equipment is being developed and tested with the support of the German Federal Ministry for the Environment. One such system adds a special battery inverter with an AGM (absorbent glass mat) lead acid battery to the solar inverter; this system is already commercially available as a back-up system. AGM cells have the advantage of higher cycle durability and of being maintenance-free. Another system that is currently being tested in Germany and France combines solar and battery inverters with Li-ion storage.

An energy-conscious four-person household in Germany could almost fully provide for its annual energy requirements using a 5-kWp PV system. A buffer storage battery allows the household to maximise its consumption of self-generated power (Fig. 2). The PV system’s peak output at midday is stored and this energy can then be drawn down when it is needed. The direction of the energy flow changes depending on supply and demand: Excess power is stored or fed into the grid, and electricity is drawn from the grid when the battery is flat and the system is not generating enough power (Fig. 3).

**Backup system with AGM batteries**

One such system adds a bi-directional battery inverter, a switching device and the desired number of AGM cells to a conventional commercially available solar energy system. If the public grid goes down, the switching device isolates the building grid from the public grid so that the solar inverter can feed into the building grid. The battery inverter also regulates this grid and maintains the voltage, frequency and phase shift at the appropriate target values. If the PV output available at a given point in time is insufficient to supply the consumers, the battery inverter provides the difference from the battery. The battery inverter stores excess PV energy in the battery and also automatically cuts off the PV inverter when the battery is fully charged. The system design with separate PV and battery inverters makes it possible to retrofit this technology to existing systems.

**Multi-functional inverters**

Multi-functional inverters are not only used to connect PV systems to the grid. When combined with modern storage devices, they can feed into the grid or else establish a stand-alone grid in the case of a grid outage. These systems were developed based on an existing technology platform: Storage elements, new control methods, additional switching and measurement equipment and communication structures were added to conventional decentralised inverters with an output of the order of a few kilowatts. This new device feeds power into the grid and also provides the system operator with an uninterruptible power supply and allows for the use of more self-generated power. The grid operator then has to invest less in grids in order to adapt them for the increasing supply of electricity from renewable sources.

**UPS: a stand-alone island in the grid**

Stand-alone operation with the new system in the case of grid outages: The inverter establishes a stand-alone grid, and important electrical consumers such as communications equipment, lighting, heating control systems and refrigerators continue to be supplied. An inverter with UPS characteristics has to be capable of operating with two different types of control and of switching between the two with minimal interruptions. The normal state is grid-parallel operation, where the inverter acts as a power source and feeds the energy delivered by the solar generator into the power grid. The energy storage device is also monitored and charged when necessary. The device continually measures the grid parameters: In the case of a grid outage, it disconnects the connected consumers from the grid without delay and then supplies them as part of stand-alone operation.

The inverter, the energy storage device and the connected consumers form their own grid in the case of stand-alone operation. The system regulates voltage and frequency; surplus PV energy is charged to a battery which has a double-digit capacity in terms of kWh. Once the public grid becomes available again, the system switches back to grid-parallel operation after passing through a synchronisation phase.
Combined system tested in service
A total of 60 grid-connected PV systems with lithium-ion storage are being tested as part of a project supported by Germany and France. The systems in France – particularly those in overseas territories – are operated in an off-grid manner, whereas those in Germany are grid-connected. This means that half of the systems operate in areas with strong grids while the other half operate in areas with weaker grids. 80% of the systems are installed in households, and 20% in commercial facilities. Important operating data are being recorded and evaluated for the installed systems, particularly for the batteries. The aim of these tests is to optimise the use of self-generated PV power and to better integrate renewable energy sources into the supply grid. The issues investigated will include the performance of the battery. It is thus important to run batteries in such a manner as to minimise the number of battery changes required. In order to achieve financially viable operation, researchers are working on the development of permanent, cost-effective storage technologies. It is not yet economical to use storage systems solely for the purpose of further increasing the use of self-generated power because of the relatively large losses associated with the standard lead acid batteries currently in use and the considerable cost of Li-ion batteries. If lead acid batteries are employed, almost three-quarters of the solar power generated still remains available as compared to direct use or feed-in. If more expensive lithium batteries are combined with smart management of battery-charging, commercially viable operation becomes possible. These batteries have significantly better efficiency and higher cycle durability: Lead acid batteries achieve efficiencies of around 85 percent, whereas a two-year service test with domestic systems using Li-ion batteries demonstrated efficiencies of around 95 percent with a predicted service life of 20 years and a discharge level of 60 percent per day.

Systems with modern lead acid batteries are already attractive today from an economic viewpoint when solely used for UPS purposes – particularly when compared to UPS systems with no PV support.

There are many variables that determine whether it is more economical to use self-generated power or to feed it into the grid: The investment and operating costs, electricity prices and the feed-in tariff must all be considered separately here. Case-by-case calculations are also necessary because the remuneration for the use of self-generated power changes depending on the fraction of self-generated power consumed. Up to now, storage costs and storage losses have quickly cancelled out additional revenue from subsidies for the consumption of self-generated power. The result is that investors have to be motivated by ecological concerns alone. A battery capacity of around 5-10 kWh is foreseen for private systems, which corresponds to around twice the output of a PV generator. The range of batteries available is developing, and profits can be expected within a few years at the end-user prices that are being targeted.

Battery systems
The introduction of storage systems means that the consumption of self-generated PV power can be almost doubled. However, cost-effectiveness is the most important criterion here too. Viability is largely determined by the service life and cycle durability of the battery. It is thus important to run batteries in such a manner as to minimise the number of battery changes required. In order to achieve financially viable operation, researchers are working on the development of permanent, cost-effective storage technologies. It is not yet economical to use storage systems solely for the purpose of further increasing the use of self-generated power because of the relatively large losses associated with the standard lead acid batteries currently in use and the considerable cost of Li-ion batteries. If lead acid batteries are employed, almost three-quarters of the solar power generated still remains available as compared to direct use or feed-in. If more expensive lithium batteries are combined with smart management of battery-charging, commercially viable operation becomes possible. These batteries have significantly better efficiency and higher cycle durability: Lead acid batteries achieve efficiencies of around 85 percent, whereas a two-year service test with domestic systems using Li-ion batteries demonstrated efficiencies of around 95 percent with a predicted service life of 20 years and a discharge level of 60 percent per day.

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The addition of a battery storage device to grid-connected PV systems makes it possible to maximise local consumption: Power supply and power consumption can thus be controlled in a demand-oriented manner and decoupled from peak production periods. Developers expect that the consumption of self-generated PV power can be increased to between 60% and 70% using new storage technology. This will in turn help to support the continuous growth of photovoltaic technology as a contributor to the overall energy mix.

The new multi-functional inverters are becoming increasingly versatile as elements in PV systems: They contribute to the increased integration of renewable energies into the overall energy supply, as they can ease the load on grids and synchronise them thanks to their new control and feed-in capabilities. Overloading of grids can be avoided by storing excess power at peak production times or when demand is weak rather than feeding it into the grid. This energy is then available later when demand is stronger.

UPS systems are based on tried-and-tested inverter technology, and are thus easy to set up or to retrofit. Countries with unreliable grid quality and frequent power outages represent particularly promising markets for UPS systems. Very high efficiencies have already been achieved for inverters, while work is continuing on long-life, cost-effective storage solutions with better efficiencies. A shift appears to be set up or to retrofit. Countries with unreliable grid quality and frequent power outages represent particularly promising markets for UPS systems. Very high efficiencies have already been achieved for inverters, while work is continuing on long-life, cost-effective storage solutions with better efficiencies. A shift appears possible away from conventional lead-acid batteries in favour of Li-ion batteries, which have longer service lives but are more expensive.

For system operators, this system promises a secure supply and higher consumption percentages for self-generated power. Energy suppliers will benefit from reduced peak loads and the ability to access decentralised balancing energy when necessary. However, economically viable operation of battery storage systems solely for the purpose of increasing the consumption fraction of self-generated power is not yet possible because of the high costs of batteries combined with storage losses. It can be expected that PV storage systems will experience a boom if balancing energy is rewarded with appropriate remuneration as part of the establishment of so-called smart grids. Cost-effective operation of these systems will then become possible.

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