**Solutions to Chapter 8:**

Exercise 8.1: Battery Systems

a) Already at normal charging/discharging cycles of the battery, a growing layer of sulfate gradually forms which is no longer totally removed during the charging process. With this the active surface of the electrodes sinks and thus the capacity of the battery. Deep discharging amplifies this effect. Extreme deep discharging can even lead to a bending the electrodes and produce a short circuit between anode and cathode.

b) A car battery (starter battery) is optimized for the buffer mode where the battery is almost always fully charged and only short-term high currents are drawn out of the battery. The necessary thin grid-plates would sulfate quickly in the cycle mode which is used for off-grid systems. In case of deep discharging short circuits between the closely positioned plates will take place. Moreover car batteries typically show a high self-discharging.

c) The information states that the battery will have a capacity of 150 Ah if it is discharged over 10 h. Thus it can be discharged over 10 h with a current of 15 A. If the battery is instead discharged with a current of 20 A the useable capacity will be smaller. According to Figure 7.28 it will be around 140 Ah; the battery thus would be discharged in 140 Ah / 20 A = 7 h.

d) Constant Current Constant Voltage. A charge controller based on this method will first charge the battery with a constant current. When the end-of-charge voltage is reached a constant charge voltage is established by the controller. By this, the battery is fully loaded but not overloaded.

e) i) Resting series resistance of the Mosfet plays no role
ii) Startup of the circuit even after deep discharge will work automatically

Exercise 8.2: Lithium Ion Batteries

a) Advantages: Higher energy density, higher number of cycles
Disadvantages: Higher price, threat of self-ignition

b) A large number of ions is pushed into the graphite lattice by which this is expanded and possibly damaged irreversible. In case of further charging a dendrite can be formed, which can penetrate the separator and destroy the cell.

c) Non-toxic, high energy density, constant cell voltage at different charge states.

Exercise 8.3: Sodium Sulfur Batteries

a) They have to be kept at high temperature all the time, this leads to additional energy costs.

b) It serves for operational safety. In case of a break of the electrolyte, it limits the amount of sodium that can react with the sulfur.

c) As the energy storage is done in liquid form, no loss of active mass arises. This is in contrast to the lead battery where the active mass declines by the unregularly growing of the lead sulfate.

Exercise 8.4: Redox-Flow-Batterien

a) Siehe Bild 8.18

b) The Power is determined by the cell size, thus especially by the usable area of the membrane. The Capacity can be determined by the size of the electrolyte tanks.

c) Capable of deep-discharge, very high cycle number (e.g. 10.000), little self-discharging.

Exercise 8.5: Home Storage Systems

a) Costs of a kWh:

| | | |
|---|---|---|
| Costs of the storage system: | $Cost_{\text{Storage}}$: | 11,300 € |
| Gross capacity: | $C_{\text{Gross}}$: | 8.0 kWh |
| Depth of Discharge: | $DoD$: | 100 % |
| Storage total efficiency: | $\eta_{\text{Storage}}$: | 94 % |
| Cycle lifespan at *DoD*: | $N_{\text{Cykles}}$: | 10,000 |
| Calendric lifespan: | $T_{\text{Livespan}}$: | 20 a |

During its lifespan, the system can store and take out again the following amount of energy:

$$W_{\text{Usable}} = 8\ \text{kWh} \cdot 1.0 \cdot 0.94 \cdot 10{,}000 = 75{,}200\ \text{kWh}$$

Thus, the specific costs for a kWh result to:

$$cost_{\text{Storage}} = \frac{Cost_{\text{Storage}}}{W_{\text{Total}}} = \frac{11{,}300\ \text{Euro}}{75{,}200\ \text{kWh}} = \underline{15\ \text{Cent/kWh}}$$

b) Limitation of the grid-exchange power:
By storing the solar energy the maximum feed-in power can be limited. Additionally, the stored energy can be used to also reduce the maximum power, which is taken from the grid.

c) 1. Limitation of the maximum admissible power output of the PV plant to 50 % of the plant´s nominal power.
2. Provision of a data interface to facilitate the remote control of PV plant and storage by the grid operator

Exercise 8.6: Off-grid Systems

a) A classical Solar Home System consists of a 12 V or 24 Volt system with solar module, solar battery, charge controller and DC-operated loads. Typical loads are energy saving lamps, radio, television and mobile rechargers.

b) In a hybrid system additionally to the solar generator including battery and charge controller other energy sources are used. Typical devices are wind generators, diesel generators, fuel cells etc. The advantage of such a hybrid system lies in the fact that independent of the weather conditions a high security of supply is reached and that the solar generator can be dimensioned relatively small.