Solutions to Chapter 7:

Exercise 7.1: Buck Converter

a) See Figure 7.4.

- Capacitor C_1: In case of a solar module at the input the capacitor serves as a buffer storage for the solar energy.
- Mosfet: Serves as a fast, wear-free and controllable switch
- Choke coil L: Ensures a continuous current at the output
- Capacitor C_2: Serves to smooth the output voltage
- Diode D: Flyback diode, which enables that the current an continuously flow even when the Mosfet is switched off

b) In case of a high switching frequency small inductors and capacitors can be used without running into the undesired discontinuous mode.

c) High switching frequencies cause higher switching losses. Therefore suitable fast, low-loss switches (e.g. of silicon-carbide) should be used.

Exercise 7.2: Feed-In Variations

See Figures 7.8 und 7.9.

Exercise 7.3: Inverter Variations

a) See Section 7.2.2.

b) The Current curve is almost exactly sinusoidal and therefore enhances the quality oft he grid voltage.

c) i) In the case of thin film modules.
ii) In the case of special c-Si modules (e.g. Sunpower, Evergreen).
iii) In the case of all modules, which are not explicitly approved for the operation with inverters without transformers.

d) It is used when a galvanic isolation is desired and one simultaneously wants to prevent the disadvantages of an inverter with mains transformer (poor efficiency, high weight etc.).

e) i) The grid is symmetrically supplied.
ii) The momentary value of the fed-in power is nearly constant so that only small storage capacitors are necessary in the inverter.
iii) Two additional switching elements (50 % more) facilitate 200 % more power.

Exercise 7.4: Inverter Dimensioning

Data from Table 6.1 and 7.2 as well from Figure 7.22:

Solar module:

V_{OC} = 29.7 V, V_N = 24.4 V
I_{SC} = 8.7 A, I_N = 8.1 A
P_N = 200 Wp TC_U = -0.34 %/K

Inverter:

V_{DC_N} = 350 V, V_{MPP} = 333 to 500 V
V_{Inv_Max} = 700 V, I_{Inv_Max} = 25 A
P_{DC_N} = 8.25 kW, P_{AC_N} = 8 kW

a) $V_{OC\_(-10°C)} \approx V_{OC} \cdot [1 + TC_U \cdot (\vartheta - \vartheta_{STC})] = 29.7\text{ V} \cdot [1 - 0.34\text{ \%/K} \cdot (-10\text{ °C} - 25\text{ °C})] = \underline{33.2\text{ V}}$

$$n_{Max} = \frac{U_{Inv\_Max}}{V_{OC\_(-10°C)}} = \frac{700\text{ V}}{33.2\text{ V}} = 21.1 = \underline{21\text{ modules}}$$

b) $V_{MPP\_Modul(70°C)} \approx V_{MPP} \cdot [1 + TC_U \cdot (\vartheta - \vartheta_{STC})] = 24.4\text{ V} \cdot [1 - 0.34\text{ \%/K} \cdot (70\text{ °C} - 25\text{ °C})] = \underline{20.7\text{ V}}$

$$n_{Min} = \frac{V_{MPP\_Min}}{V_{MPP\_Modul(70°C)}} = \frac{333\text{ V}}{20.7\text{ V}} = 16.1 = \underline{17\text{ modules}}$$

c) $$n_{String\_Max} = \frac{I_{Inv\_Max}}{I_{String\_Max}} = \frac{I_{Inv\_Max}}{1.25 \cdot I_{MPP}} = \frac{25\text{ A}}{1.25 \cdot 8.1\text{ A}} = 2.5 = \underline{2\text{ strings}}$$

Thus minimum 1 x 17 modules and maximum 2 x 21 = 42 modules can be installed.

d) With regard to the power dimensioning a design factor of maximum 1 is recommended. With Equation (7.21) this leads to:

$\Rightarrow P_{STC} \leq 1 \cdot P_{AC\_N} = 8\text{ kW}$

Therefore the optimal plant configuration comprises tow strings with 20 modules each. Possible were also 19 per string or - if necessary - 21 modules per string.

Exercise 7.5: 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) 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 7.6: 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.

b) In a hybrid system additionally to the solar generator with 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 is 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.