for decades and still remains so. Lead acid batteries cover a wide range of applications from SLI batteries in cars and trucks to uninterruptible power supplies, from load-levelling batteries for grid stabilisation to traction batteries (fork-lift trucks and others) and last but not the least autonomous power supply systems. Different battery designs have been developed for different applications to cover the various requirements.

Lead acid is by far the cheapest battery type in comparison to all other readily available storage systems with appropriate characteristics according to the list given in Table 18.1. A major drawback of the lead acid battery is the low specific gravimetric energy content due to the high molecular weight of lead. However, this is not a parameter of major importance in autonomous power supply systems as the battery is stationary.

It is expected that the lead acid battery will remain as the working horse for autonomous power supply systems for many more years, probably decades. Therefore, this chapter gives a deeper insight into the lead acid battery. The lead acid–battery chemistry, a detailed description of the battery design, ageing effects and recommendations for the operating strategy are the main topic of the following sections.

18.4.7.1 Lead acid–battery chemistry

Lead acid batteries in the charged state consist of a positive electrode with lead dioxide (PbO_2) and a negative electrode with lead (Pb) as the active materials. Both electrodes contain a support grid, which is made from hard lead alloys. Sulphuric acid (H_2SO_4) diluted to 4M or 5M is used as the electrolyte. The following reaction equations describe the main reaction:

Positive electrode $$PbO_2 + 3H^+ + HSO_4{}^- + 2e^- \rightleftarrows PbSO_4 + 2H_2O \qquad (18.5)$$

Negative electrode $$Pb + HSO_4{}^- \rightleftarrows PbSO_4 + H^+ + 2e^- \qquad (18.6)$$

Cell reaction $$Pb + PbO_2 + 2H^+ + 2HSO_4{}^- \rightleftarrows 2PbSO_4 + 2H_2O \qquad (18.7)$$

PbO_2 and Pb are both converted to lead sulphate $PbSO_4$ during discharging (double sulphate theory). Sulphuric acid as the electrolyte is used up during the discharging of the battery. Therefore, the concentration of the sulphuric acid decreases linearly with the state of charge. This is an important difference with respect to almost all other battery types, where the electrolyte has only the function of an ion conductor. In lead acid batteries, it is in addition the source for the ions to counterbalance the charge dissolved in the electrolyte from the electrochemical process. Therefore, the electrolyte is subject to "structural" changes like the electrode materials themselves. This is an important reason for several battery characteristics and ageing effects as will be discussed later.

In Section 18.2.1.2, it was described that during charging and discharging not only the electrochemical process described by the Bulter–Volmer equation occurs but a chemical process takes place as well. Figure 18.10 shows a schematic of this overall process for the lead electrode which is described by equation (18.6).

The charged electrode consists of lead (Pb) in the solid state. When a discharge current occurs, two electrons are withdrawn from the metallic lead and dissolution of Pb^{2+} ions into the electrolyte occurs. Through diffusion, the charged ions are transported