### *18.4.7.6.2 Deep-discharge protection*

Lead acid batteries suffer from deep discharge for several reasons. An increasing depth of discharge results in a decreasing acid concentration and due to the increased sulphate solubility in accelerated sulphation (Section 18.4.7.4.2), corrosion (Section 18.4.7.4.3) and higher sensitivity to freezing (Section 18.4.7.4.7). Further, the mechanical stress is increased because of the changes in the specific volume of the active materials and in long battery strings, the risk of reverse charging of single cells (Section 18.4.7.4.6) increases.

Therefore, the maximum depth of discharge should be limited during normal operation.[13]

While choosing the appropriate DOD for the operation strategy, the data-sheet information given by the manufacturers should be analysed. They often give the number of cycles during the lifetime of a battery as a function of the depth of discharge. However, for the system design the number of cycles is not the most important parameter. The level of capacity throughput that can be realised during the battery lifetime is of more relevance. A cycle with 50% DOD means that only 50% of the capacity is used and therefore the overall capacity throughput for, for example, 200 cycles with 50% DOD is equivalent to 100 cycles with 100% DOD. However, from the point of view of the system design a battery which is limited to 50% DOD during normal operation must have double the size with respect to a battery with 100% DOD during normal operation. This is worthy of mention because batteries are always limited by the capacity throughput on one hand and by operation life on the other hand. Therefore, it makes no sense to operate a battery which is, for example, rated for 10 000 cycles at 20% DOD in autonomous power supply systems even though this might promise the highest capacity throughput. Assuming that on a daily basis 10 000 cycles take place, it would take more than 25 years to achieve this. However, the battery lifetime would not last that long due to other ageing processes.

Figure 18.24 shows for two different batteries the cycle life as a function of the DOD (data taken from data sheets) and the resulting capacity throughput. It is obvious that for the battery Type 2, the capacity throughput is almost independent of the DOD but for battery Type 1 there is a strong dependency leading to higher throughputs at lower DODs.

For practical purposes, the following "rules" can be used, which have proved their suitability in the field. In Classes 1 and 2 (Section 18.3.2), the maximum DOD should be 60 to 70% and in Classes 3 and 4, 80 to 90%. The lower values are for flooded batteries and the higher values are for VRLA batteries. Low-cost "solar batteries" should be operated to a maximum of 50% DOD. It is very important to take into account that the mentioned values for the DOD are given on the basis of the $C_{10}$ capacity. Using, for example, 80% of the $C_{100}$ capacity means using more than 100% of the $C_{10}$ capacity and this is hazardous.

Control of the maximum DOD can be realised either by deep-discharge disconnecting voltage or on the basis of the state of charge. Most commercial charge controllers

[13] As stated in the subsection on charging, a complete discharge of the battery to 100% DOD twice a year is of benefit to the battery. This is not in contradiction to a limited DOD during normal operation. The defined discharge is done within a short time and is followed directly by complete recharging of the battery. In normal operation, discharge times and duration in deep states of charge can be very long and the next full charging may occur only weeks or month later.