

according to the average battery temperature. Fail-safe behaviour is crucial in case of a temperature-monitoring malfunction, for example, due to broken sensor wires.

- The thresholds must be stable over temperature and time.
- If relays are used as control elements, the minimum switching period should be 1 to 5 min.
- The charge controller should be able to charge totally flat batteries. As a minimum requirement, charging should start from a cell voltage of 1.5 V.
- The battery voltage can be monitored by separate sensor wires. This is recommended if the battery wiring is long and of low cross-section. Fail-safe behaviour is crucial in case of broken sensor wires.
- The charge controller should be able to automatically perform gassing charging or equilibration charging according to the manufacturer's recommendations.
- It must be possible to prevent gassing charging in case of valve-regulated batteries (Gel- or AGM-VRLA batteries).
- The output voltage must be limited to safe values in the case of system operation without a battery, for example, due to unintended disconnection of the battery, wire breakage or blowing of the battery's fuse.

2. Deep-discharge protection.

- Deep-discharge protection is mandatory for a long service life. Only when the function of the system is more important than the battery life (e.g. in SOS telephones), deep-discharge protection can be omitted.
- The threshold voltages should be adjustable in a range of 1.5 to 2.0 V/cell. The adjustment range should not extend beyond this range to prevent extremely incorrect settings.
- The threshold should not be temperature-compensated.
- The threshold must be stable over temperature and time.
- The threshold can automatically adapt to the instantaneous battery current.
- The threshold can be based on the battery's actual state of charge.
- A time delay of 10 to 60 s should be implemented between undershooting of the threshold and the actual load disconnection.
- A warning signal can be given out when the deep-discharge condition is approached, for example, switch on a yellow LED 30 min before load disconnection at full load.
- Load disconnection can be performed according to load priorities.
- After load disconnection, only minimum current ($<I_{10,000}$) should be drawn from the battery. This can be achieved by appropriate design, for example, displaying of the current system status only on demand.
- The threshold for load reconnection should be relatively high, for example, >2.1 V/cell.
- A time delay of 10 to 60 s should be implemented between overshooting of the reconnection voltage threshold and the actual reconnection of the load.

3. Efficiency.

- The parasitic consumption of the charge controller should be less than 0.2% of the PV generator's power, for example, <8 mA in a 12-V/50-W controller.