not constant and depends on the battery capacity, the state of charge, the charging or discharging current as well as the voltage hysteresis. It can vary from milliseconds to minutes. If mechanical relays are used as switching elements, the period should not be shorter than 1 to 5 min.

The second control regime found in practice is pulse-width modulation (PWM). In principle, it works like the two-step controller described above, but the switching frequency of the control element is fixed and determined by a clock generator. The typical frequency is about 100 Hz. In the CC phase, the switch is permanently closed and the full charging current flows into the battery. When approaching the end-of-charge voltage, the duty cycle (the ratio between the charging time and the cycle period) will be reduced towards zero by the pulse-width modulator. As mentioned above, the average charging current will drop and the battery voltage is kept constant.

One advantage of PWM controllers is that the switching frequency is known and constant. EMC problems can be solved more easily, and also monitoring of the average charging current becomes simpler.

19.1.1.5 Matching DC/DC converter, MPP trackers

Both the battery voltage and the PV generator voltage vary over a wide range during operation due to the changing state of charge and boundary conditions such as temperature and insolation. When directly coupled, this leads to a certain mismatch between the actual and the optimum operation voltage (MPP voltage) of the solar generator and therefore causes energy losses.

The mismatch can be overcome by introducing a matching DC/DC converter (MDC) that de-couples the characteristic curves of the PV generator and the battery. The power stage of these converters corresponds to the well-known topologies such as buck, boost or inverting converters. The control section is specially tailored to the PV conditions and consists of two control loops: one for the input and the other for the output. As long as the end-of-charge voltage has not been reached, the input voltage controller keeps the PV generator voltage at a constant level by appropriate adjustment of the DC/DC converter's switching regime (PWM). The voltage level can either be fixed (CV mode) or can track the actual MPP by an appropriate searching strategy (MPP tracking, MPPT). When the end-of-charge voltage is reached, the output voltage controller takes over and keeps the battery voltage at a constant level. The PV generator's operating point then shifts towards open-circuit conditions.

Numerous strategies and algorithms have been developed to find and track the MPP of a solar generator. They can be grouped into two categories:

- Indirect MPP trackers
  This type of MPP tracker estimates the MPP voltage by means of simple assumptions and measurements.
  Some examples from practice include the following:
  - The operating voltage of the solar generator can be adjusted seasonally. Higher MPP voltages can be expected in winter due to lower cell temperatures and vice versa.
  - The operating voltage can be adjusted according to the module temperature.