  - The operating voltage can be derived from the instantaneous open-circuit voltage by multiplication with a constant factor, for example, 0.8 for crystalline silicon solar cells. The open-circuit voltage is measured periodically (e.g. every two seconds) by disconnecting the load for one millisecond.

  The advantage of the above-mentioned procedures is simplicity, but they only give an estimate of the optimum operating point. They are not able to adapt to changing solar generator characteristics due to ageing or soiling.

- Direct MPP trackers
  In these systems, the optimum operating voltage is derived from measured currents, voltages or the power of the PV generator. Therefore, they are able to react to changes in the generator's performance.
  Some examples include the following:
  - Periodic scanning of a part of the $I-V$ curve. Here, the operating voltage of the module is varied within a given voltage window by means of the DC/DC converter. The maximum module power is determined and then the operating voltage is adjusted to the corresponding voltage level. In practice, it is much easier to measure the output current of the DC/DC converter and to maximise it. This leads to the same result as above.
  - "Mountain-climb algorithm". Here, the operating voltage is periodically changed in small steps. The increment can either be constant or can be adapted to the instantaneous operating point as shown in Figure 19.8. If the module's power (and therefore the charging current) increases from one step to the next, the search direction is retained; otherwise it is reversed. In this way, the MPP is found and the operating point oscillates around the actual MPP.

The above-mentioned losses due to mismatch are mostly overestimated. Particularly, if the components are chosen properly (e.g. modules with 30 to 33 cells for 12-V systems), the energy losses are on the order of a few percent when using direct coupling

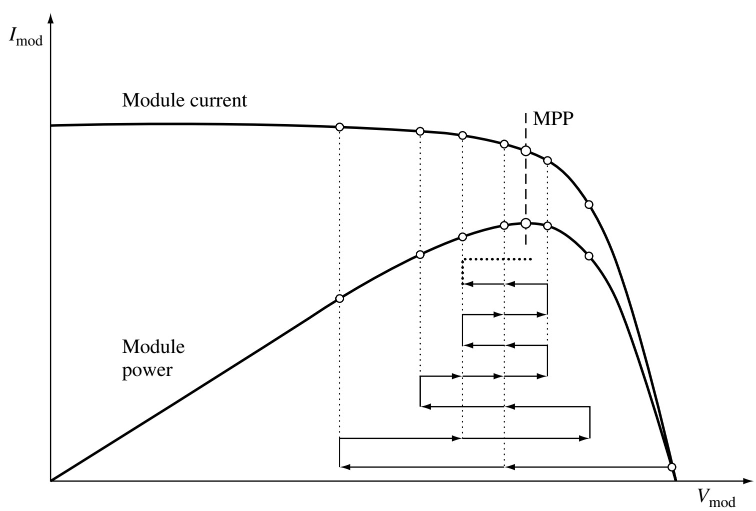

Figure 19.8 Working principle of the "Mountain-climb" MPP-tracking algorithm