the power losses are zero in both cases because either voltage or current at the control element is zero.

Once again, it must be pointed out that the additional energy gained in this way is normally not relevant for the functioning of the PV system. By contrast, the reduction of heat generation leads to savings in component costs (heat sinks) and to an increased reliability due to lower component temperatures.

In a series controller as shown in Figure 19.4(a), the charging current will be controlled by an element switched in series with the solar generator.

In early charge controllers, relays were used as switching elements, but today semiconductor switches like MOS-FETs are used in almost every application.

One advantage of the series controllers is that in addition to PV generators, they can be used for other power sources that are not being tolerant to short circuits such as wind turbines. Furthermore, the voltage stress for the switch is lower compared to the shunt controller described below. With a fully charged battery, the solar generator operates in the open-circuit mode. In this operation mode, no module overloading due to partial shading can occur. On the other hand, the solar generator current is fully turned on and off, which can lead to greater EMC problems compared to shunt controllers.

In the past, the series controller was accused of having fundamentally higher losses. This is no longer true since low-resistive semiconductor switching elements have been used – the losses can be even lower than for shunt controllers. Furthermore, some early series controllers did not start with completely flat batteries because they did not have enough energy to activate the series switch. This problem can easily be solved by powering the controller from the PV module instead of from the battery.

A parallel or shunt controller as shown in Figure 19.4(b) makes use of the electrical characteristic of PV modules that they are infinitely tolerant to short circuits.

In the constant-current charging phase, the module current flows through the blocking diode D1 into the battery. When the end-of-charge voltage has been reached, the PV generator is short-circuited by the switch S1. The blocking diode now prevents the reverse current flowing from the battery into the switch. Furthermore, it suppresses the discharging currents into the PV generator during the night.

In contrast to the series controller, this kind of charge controller will also reliably start charging with a fully discharged battery, because the switch can be energised only when the battery is fully charged.

The hybrid charge controller is a modified shunt controller, in which the blocking diode is bypassed by a second transistor in the charging phase. This reduces the power dissipation in the controller, which leads to smaller heat sinks and lower thermal stress. Furthermore, the reduction of the voltage drop supports the use of cost-optimised PV modules with a smaller number of series-connected cells, for example, 30 to 33 crystalline-silicon cells for 12-V systems.

Another variant of the shunt controller is the partial-shunting controller according to Figure 19.5. Here, only some of the series-connected modules are shunted via taps.