20.13 ENERGY YIELD OF GRID-CONNECTED PV SYSTEMS

The output of grid-connected PV systems is the output from the PV array less the losses in the inverter. The output from the PV array has been considered in detail in this chapter, and the performance of inverters is described in Chapter 19. As far as inverters are concerned, it is important to account for the fact that the instantaneous efficiency, η_y, depends on the ratio between the actual power delivered to the grid P_{AC}, and the rated power of the inverter, P_{IMAX}. This dependence may be represented by [85]

$$\eta_i = \frac{p}{p + k_0 + k_{i1}p + k_{i2}p^2} \tag{20.89}$$

where $p = P_{AC}/P_{IMAX}$ and k_0, k_{i1} and k_{i2} are parameters characteristic of the inverter defining its electrical behaviour. k_0 is the quiescent power consumption, k_{i1} represents the losses that depend linearly on the current (voltage drop across diodes, etc.) and k_{i2} represents the losses that depend on the square of the current (resistive losses, etc.). These parameters can be obtained from the inverter efficiency curve. Depending on quality level, input voltage and rated power, the loss parameters of existing inverters have a spread of more than a factor of 10. Average values, in percentage, are $k_0 = 2$, $k_{i1} = 2.5$ and $k_{i2} = 8$, leading to 85% typical energy efficiency. Very good inverters reduce these values to $k_0 = 0.35$, $k_{i1} = 0.5$ and $k_{i2} = 1.$, leading to 95% typical energy efficiency.

To describe the effect of no-load shut-off, the standby self-consumption k'_0 is used. It is the value to which the operating self-consumption (k_0) is reduced during shut-off ($k'_0 < k_0$). Reduction of self-consumption improves the low- and medium-power efficiency, which is most important for PV applications. The loss fractions due to self-consumption sum up to considerable losses in PV systems. In comparison, the sum of the load dependent losses (due to k_1 and k_2) is 1.5 to 7 times smaller.

Standard methods for performance analysis of PV grid-connected plants have been introduced in the JRC Ispra Guidelines [86] and extended and improved by HTA Burgdorf [87]. Global performance is appropriately described by the so-called *performance ratio* (*PR*), which is the ratio of AC energy delivered to the grid, E_{AC}, to the energy production of an ideal, loss-less PV plant with 25°C cell temperature and the same solar irradiation. This gives a good indication of how much of the ideally available PV energy has actually been used. It is given by

$$PR = \frac{E_{AC}}{\dfrac{G_y(\beta, \alpha)}{G^*} \cdot P^*_M} \tag{20.90}$$

Other interesting parameters are the *Reference Yield*, $Y_r = G_y(\beta, \alpha)/G^*$, the *Array Yield*, $Y_a = E_{DC}/P^*_M$, where E_{DC} is the DC energy generated by the PV array, and the *Final Yield*, $Y_f = E_{AC}/P^*_M$. All the three have units of time, and allow us to distinguish between the losses due to the PV array, and the losses associated to the inverter and to the operation of the system. Capture losses, $L_C = Y_r - Y_a$, are defined as the energy losses, expressed in hours per day of PV array operation at STC power output, caused by: cell temperatures