Table 20.9 Power distribution of the yearly irradiation for a low and a high latitude location

Location	$G_y(\beta_{opt})$ [kWh/m^2]	Percent of irradiation in different ranges of irradiance in [W/m^2]				
		<200	200–500	500–800	>800	Total
Jaen	2040	5.8	23.6	44.7	25.9	100
Copenhagen	1190	13.9	30.7	35.7	19.7	100

higher than 25°C, losses in wiring and protection diodes, poor module performance at low irradiance, partial shading, snow and ice coverage, module mismatch, operation of the array at a voltage other than its maximum power point, and spectral and angular losses. *System losses*, $L_S = Y_a - Y_f$, are the losses due to inverter inefficiencies. It must be noted that $PR = Y_f/Y_r$.

Energy losses in good PV grid-connected systems are about $L_C = 15\%$ and $L_S = 7\%$, which lead to $PR \approx 0.78$. However, reported experimental values have ranged from 0.65 to 0.72. The main reason for such *PR* reduction is that the actual power of installed PV arrays is often below the rated power declared by the manufactures [88].

The power distributions of solar irradiation are different for varied geographical latitudes. In places of high latitude, with very cloudy weather, the solar irradiation is almost evenly distributed over a wide range of power scale; while in low latitude places, with predominantly clear sky, the higher power range is enhanced. Table 20.9 presents the distribution in different irradiance classes of the total yearly irradiation over an optimally tilted surface, as obtained from the *TMY* of Copenhagen [89] ($\phi = 55.7°$) and Jaen-Spain [90] ($\phi = 37.8°$). Surprisingly, the energy content at low irradiances ($G < 200$ W/m^2) is relatively low in both places. This may appear counter-intuitive, but it is easily understood when considering the difference between time and energy distribution. For example, in Copenhagen, the low irradiance (<200 W) accounts for only 13.9% of the total annual irradiation, despite it occurring during 2461 h/year, which represents 55% of the total daily time. That leads one to question the idea, sometimes defended in PV literature [91], that PV module performance at low irradiances is very relevant for cloudy climates. As a matter of fact, empirical evidence that efficiency at low light levels is scarcely relevant is found in the literature [92].

However, because the most commonly occurring irradiation corresponds to medium irradiances, an energetic advantage can be obtained by selecting the inverter size smaller than the PV generator peak power, that is, $P_{IMAX} < P_M^*$. The corresponding reduction of relative inverter self-consumption and losses may compensate the possible energy loss by an inverter power limit lower than the maximum PV output power. Recommended values of P_{IMAX}/P_M^* range from 0.6 (high latitudes) to 0.8 (low latitudes) [85, 93].

20.14 CONCLUSIONS

Methods to estimate all the solar radiation components incident on any arbitrarily oriented surface and at any time of the year have been presented. The only required input