obtained by

$$\frac{1}{\eta^*} \cdot \frac{d\eta}{dT_c} = \left(\frac{P_M}{P_M^*} \cdot \frac{G^*}{G_{eff}} - 1\right) \cdot \left(\frac{1}{T_c - T_c^*}\right) = -0.004/^\circ C$$

This means the efficiency decrease is about 0.4% per degree of temperature increase, which can be considered as representative for c-Si.

It should be noted that, depending on the input data availability, other PV- generator modelling possibilities exist. For example, commonly I_M^* and V_M^* are given in the specifications in addition to their product P_M^*. Then, the series resistance can directly be estimated from equation (20.62). This leads to

$$R_S^* = \frac{V_{OC}^* - V_M^* + V_t \ln\left(1 - \dfrac{I_M^*}{I_{SC}^*}\right)}{I_M^*} \tag{20.72}$$

20.10.2 Second-order Effects

The model presented in the previous section is based only on standard and widely available information, which is an undeniable advantage, in particular for PV-system design. Furthermore, it is simple to use. However, it can be argued that such simplicity is at the price of neglecting the following:

- The effects of the parallel resistance
- The influence of the cell temperature in the short-circuit current.
- The influence of the irradiance in the open-circuit voltage.
- The non-linearity due to low irradiance.
- The spectral effects.
- The effects of wind.

It should be recognised that differences between expected and real energies delivered by PV modules are often mentioned in the literature [58]. Hence, it is worth reviewing the importance of each one of these previously neglected factors, with the aim of clarifying possible error sources. Many of these factors are discussed further in Chapter 16.

The influence of the parallel resistance is, to a great extent, compensated here, by the particular way of estimating the series resistance of a PV module, which assures that the maximum power of the modelled curve coincides exactly with that corresponding to the real one. Because of this, the accuracy of the model tends to be very good just around the maximum-power operation point, that is, just on the voltage region of interest.

The short-circuit current tends to increase slightly with increasing temperature. This can be attributed, in part, to increased light absorption, since semiconductor band gaps generally decrease with temperature, and, in part, to increased diffusion lengths of the