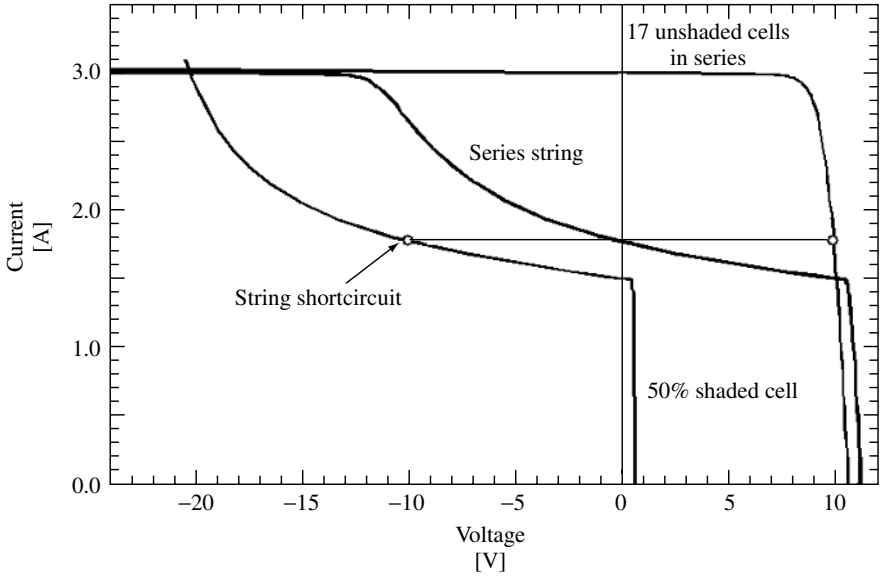

Figure 7.20 Computer simulation of the $I-V$ curves of a 50% shaded cell, showing the typical "soft" reverse breakdown, and of 17 identical cells, unshaded, in series. When series-connected with the shaded cell, the curve labeled "series string" is obtained

In order to devise the means of preventing hot spot failure from occurring, the worst case is considered. This occurs when the N-cell series string is short-circuited and a shaded solar cell is reverse-biased with the voltage of the remaining $N-1$ good devices, as shown in Figure 7.20. The minimum N that will lead to hot spot formation (i.e. the maximum N for safe operation) depends on rather uncontrollable factors, as explained. For Si solar cells of standard technology, it is around 15 to 20.

Since larger series strings are generally used, the approach followed is to put a diode (bypass diode) in parallel, but in opposite polarity, with a group cells. The number of cells in the group is chosen so that hot spots cannot be formed. When one or several cells are shaded, they are reverse-biased only to the point where the diode across the group starts forward conduction. The diode carries away the necessary current to keep the group near short-circuit.

Figure 7.21 illustrates the operation of the bypass diodes. When the current forced through the shaded substring is such that the reverse bias equals the diode threshold voltage, the bypass diode sinks all necessary current to keep the string at this biasing point thus preventing the power dissipated in the shaded cell to increase. It is also apparent that the bypass diode leads to a significant increase of output power allowing the module to keep delivering the power generated by the unaffected groups.

It is clear then that the smaller the number of cells per bypass diode, the lower the efficiency loss for a shading condition, but this means a higher cost and more complex fabrication. It has been proposed to integrate a bypass diode in each cell so that these effects will be minimized at the expense of more complicated cell processing [138].