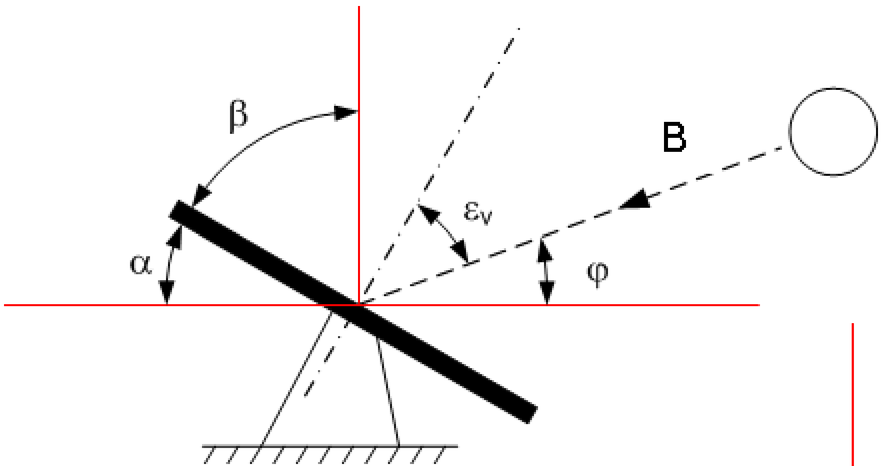
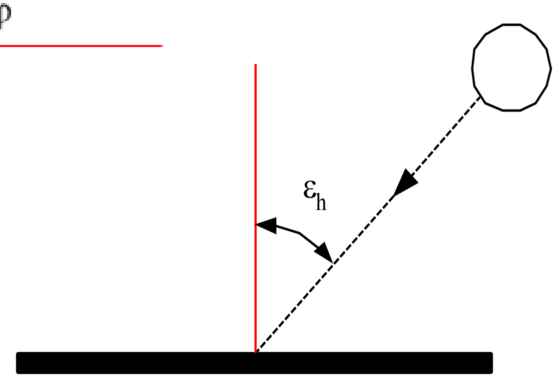
PV system operation conditions

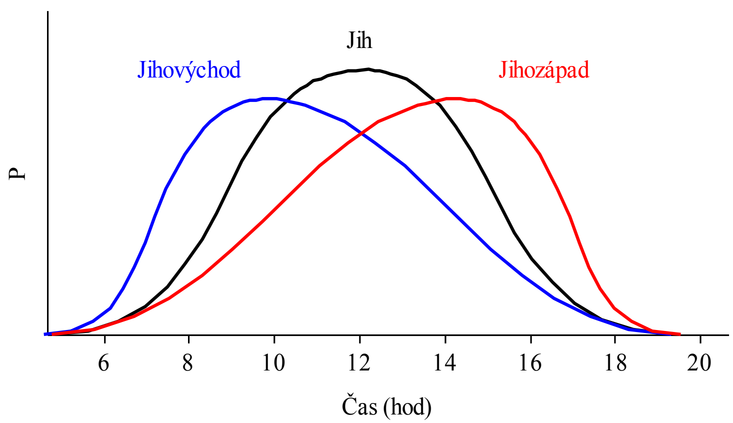
A fixed construction (orientation, tilt angle)





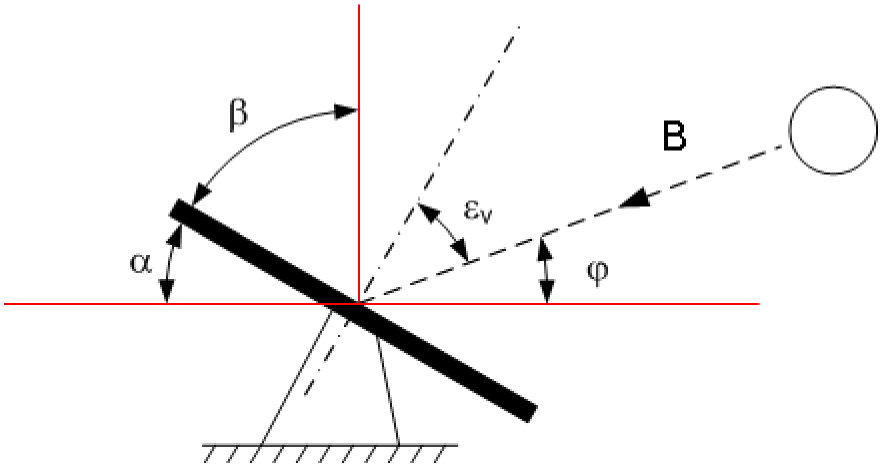
Under clear sky conditions

$$B(t) = 1367 \times 0.7^{\frac{1}{\sin \varphi(t)}} \cos \varepsilon_v(t) \cos \varepsilon_h(t)$$



Sun tracking systems

One axe tracking

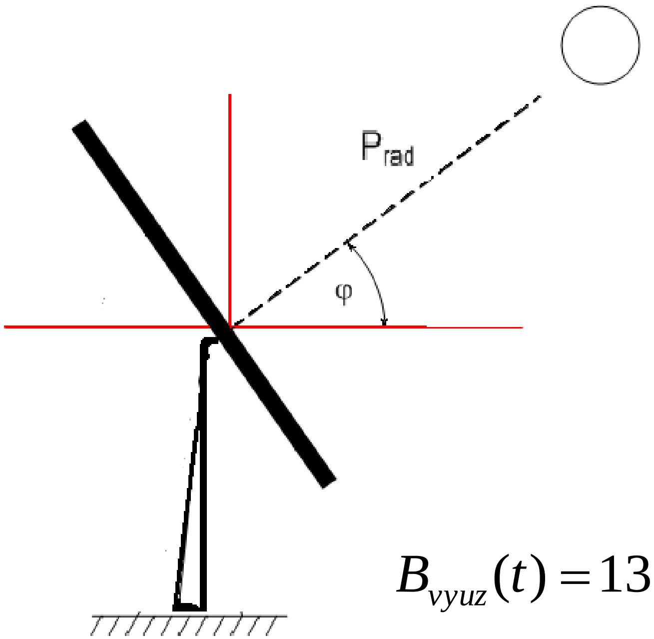


$$B_{vyuz}(t) = 1367 \times 0.7^{\frac{1}{\sin\varphi(t)}} \cos\varepsilon_v(t)$$

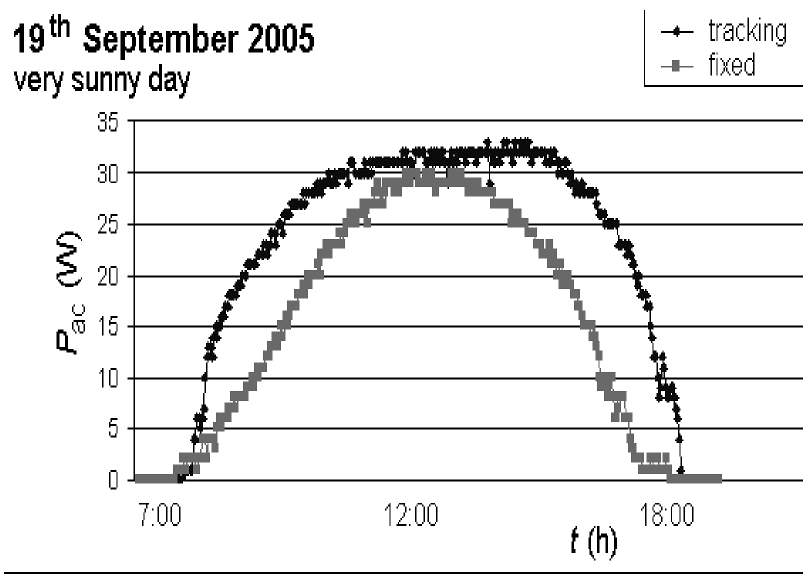
$$B_{vyuz}(t) = 1367 \times 0.7^{\frac{1}{\sin\varphi(t)}} \cos\varepsilon_h(t)$$

Sun tracking systems

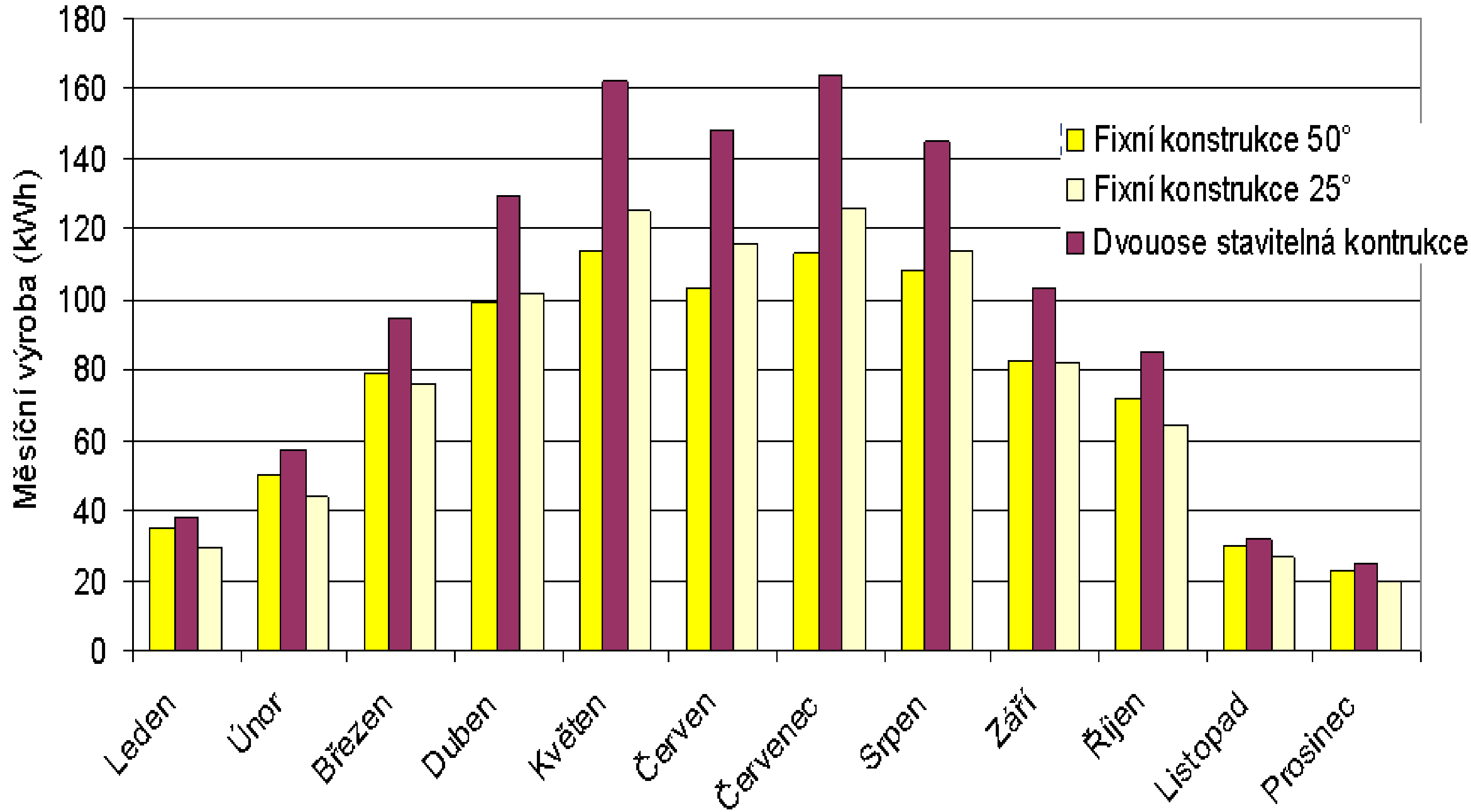
Two axes tracking



$$B_{vyuz}(t) = 1367 \times 0.7^{\frac{1}{\sin\varphi(t)}}$$



Systems with Sun tracking can produce of about 30% more energy than systems with a fixed construction



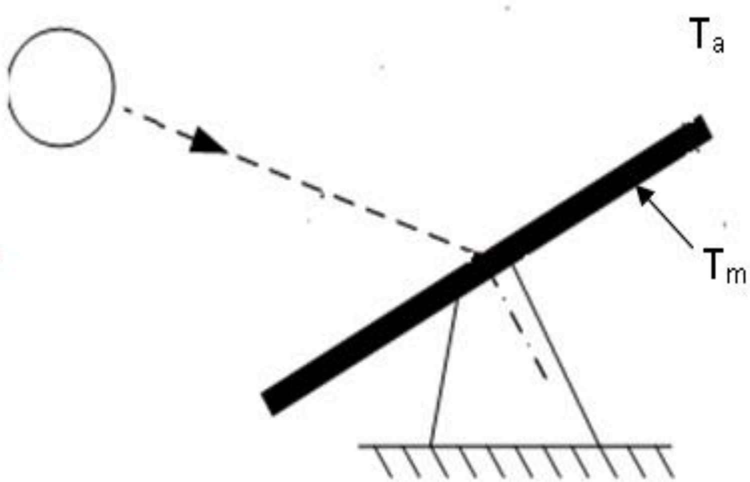
Měsíční výroba (kWh)
180
160
140
120
100
80
60
40
20
0
Fixní konstrukce 50°
Fixní konstrukce 25°
Dvouose stavitelná kontrukce
Leden
Únor
Březen
Duben
Květen
Červen
Červenec
Srpen
Září
Říjen
Listopad
Prosinec

Influence of temperature

Open circuit voltage V_{OC} depends on the cell temperature T_c

$$V_{OC}(T_c) = V_{OC}^* + (T_c - T_c^*)\frac{dV_{OC}}{dT_c}$$

$$T_c = T_m + \frac{G_{eff}}{G^*}\Delta T$$



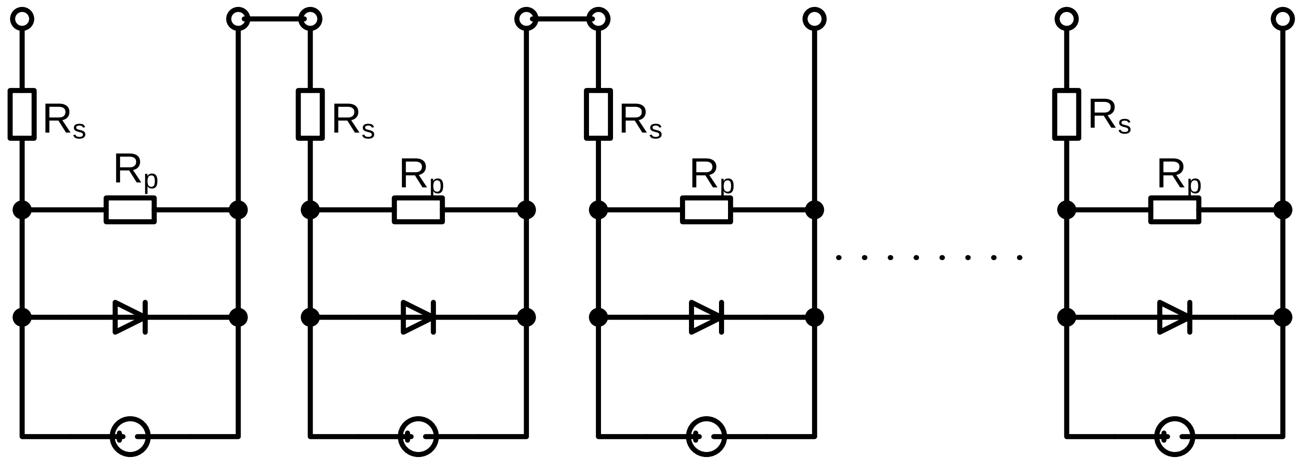
Temperature of the back surface T_m

$$T_m = T_a + \frac{G_{eff}}{G^*}\left[T_1 \exp(b v_W) + T_2\right]$$

v_w is the wind velocity

Type	T_1 [°C]	T_2 [°C]	b	ΔT [°C]
Glass/cell/glass	25.0	8.2	−0.112	2
Glass/cell/tedlar	19.6	11.6	−0.223	3

Effect of partial shading – cells in series

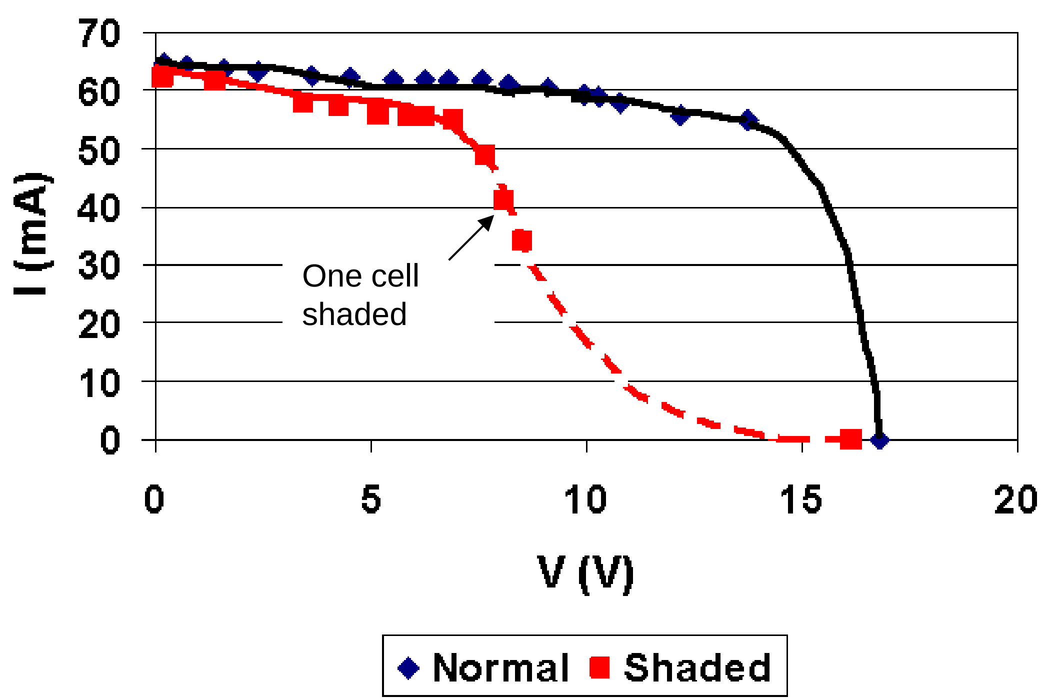


In the case of cells in series increases series resistance

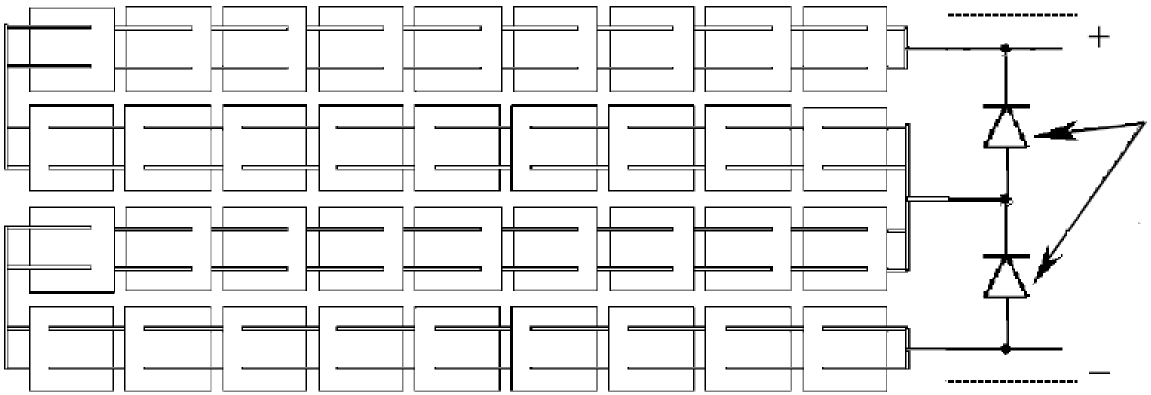
• a decrease of the output current

• a decrease of the output voltage

• a considerable decrease of the output power

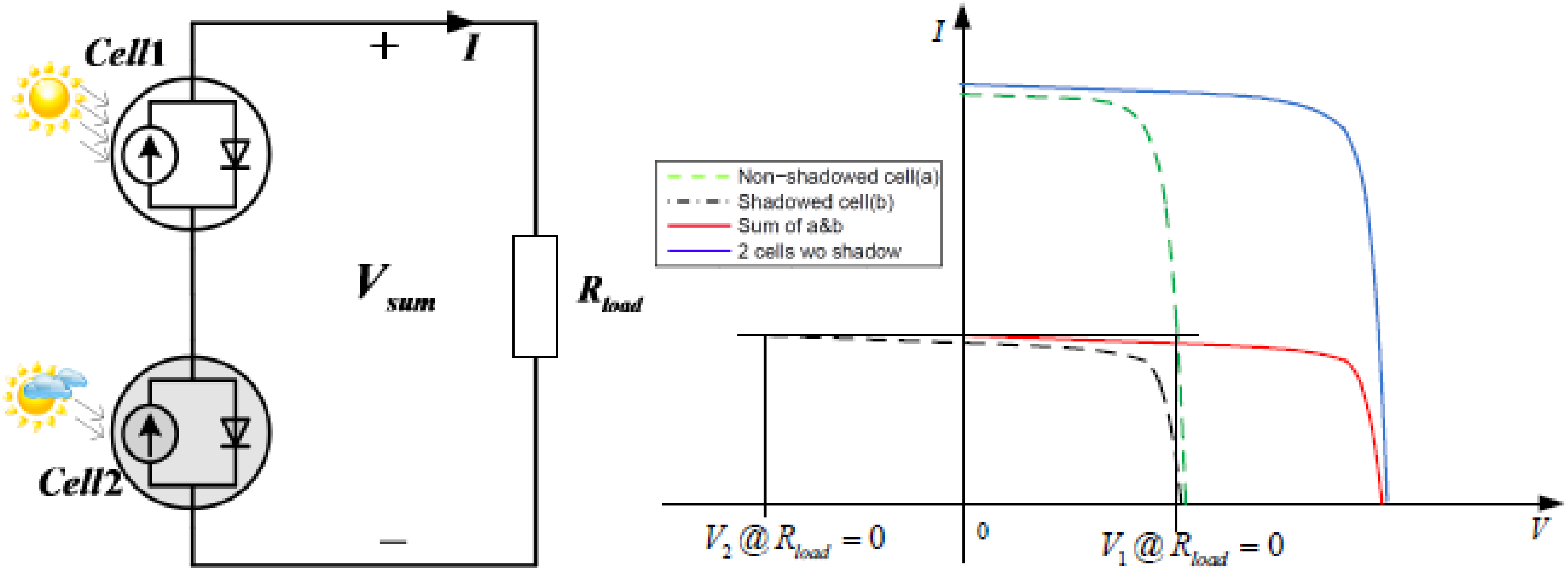


To eliminate possible hot spot origin, the approach followed is to put a diode (bypass diode) in parallel, but in opposite polarity, with a group cells



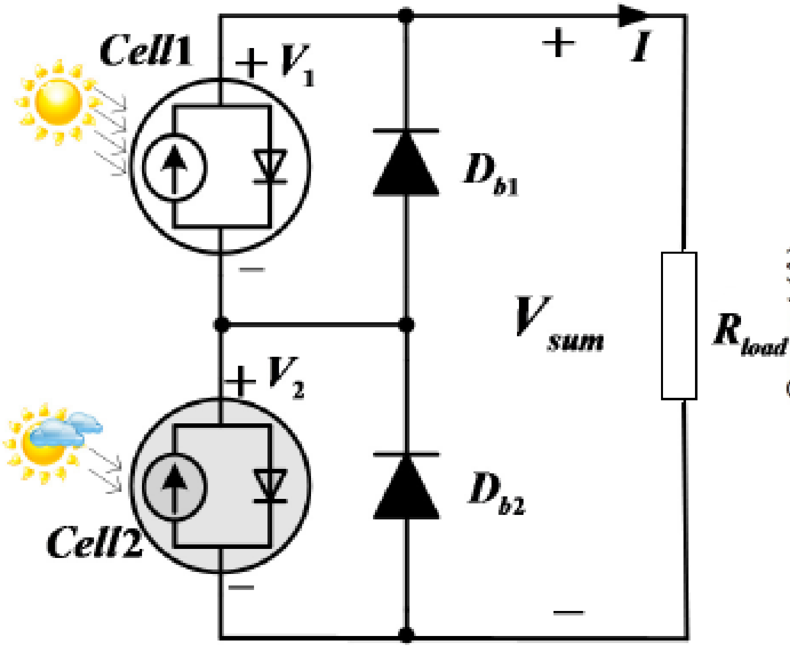
Bypass diodes are connected in the junction box 12 or 18 cells each

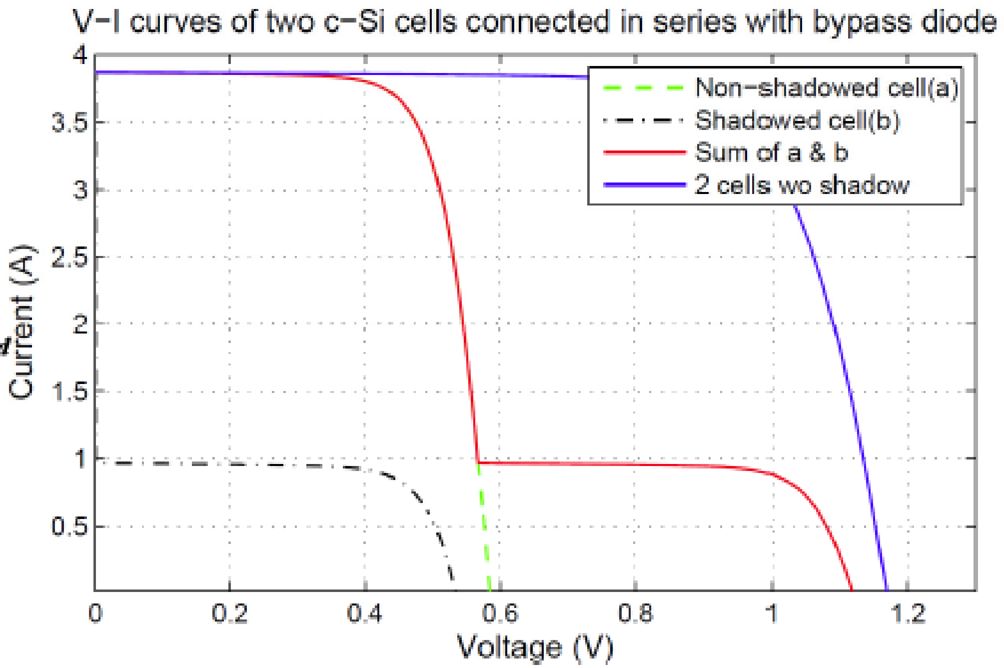
Non-uniform irradiation without bypass diodes



In case of no bypass diode, the cell with lower irradiance will limit the current

Non-uniform irradiation with bypass diodes

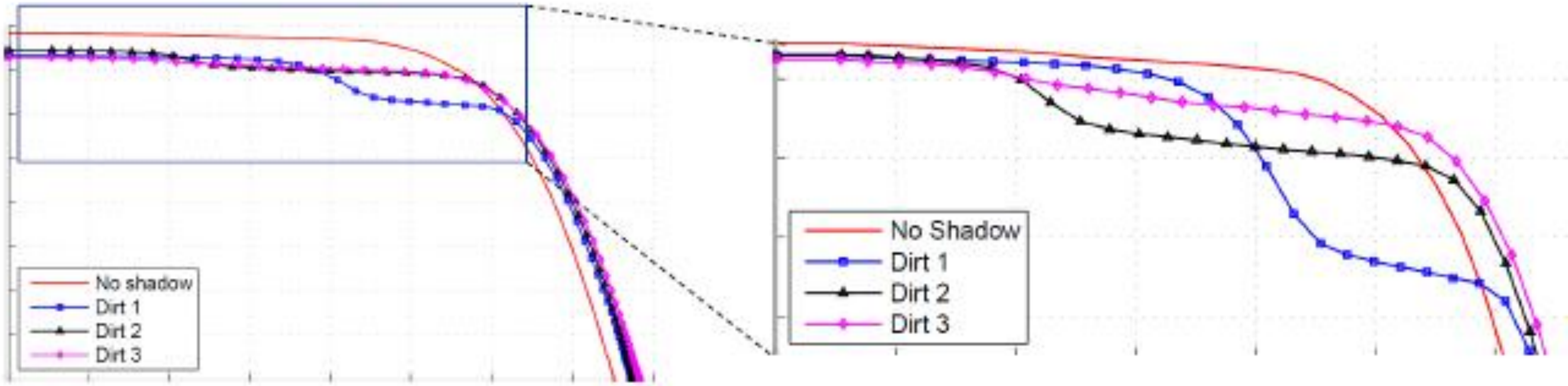




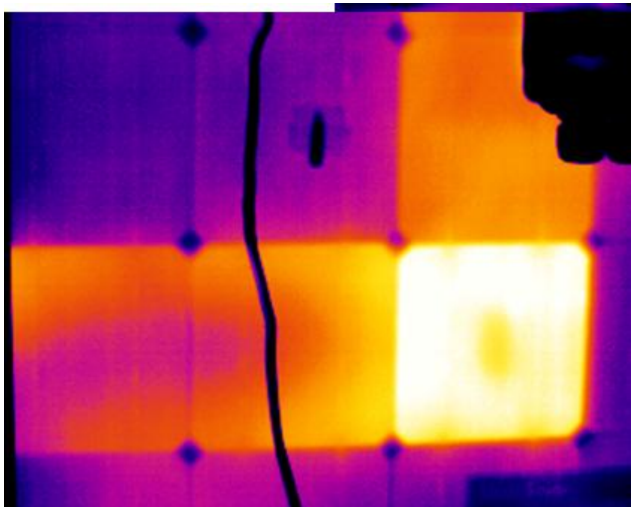
The bypass diode D_{b2} serves as path for the current, when *I* is larger than the short-circuit current of *Cell2*

Soiling on PV modules

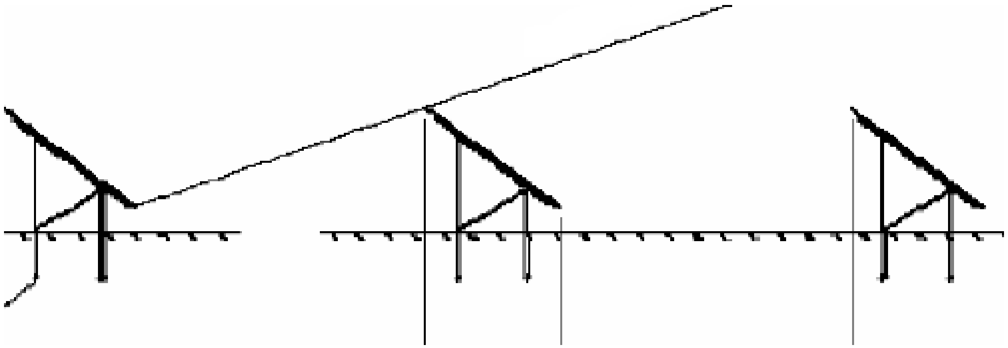
Even a small spot on a PV panel can significantly alter its characteristic



Temperature distribution on partially shaded PV module



Distances between constructions should be projected with respect to possible shading

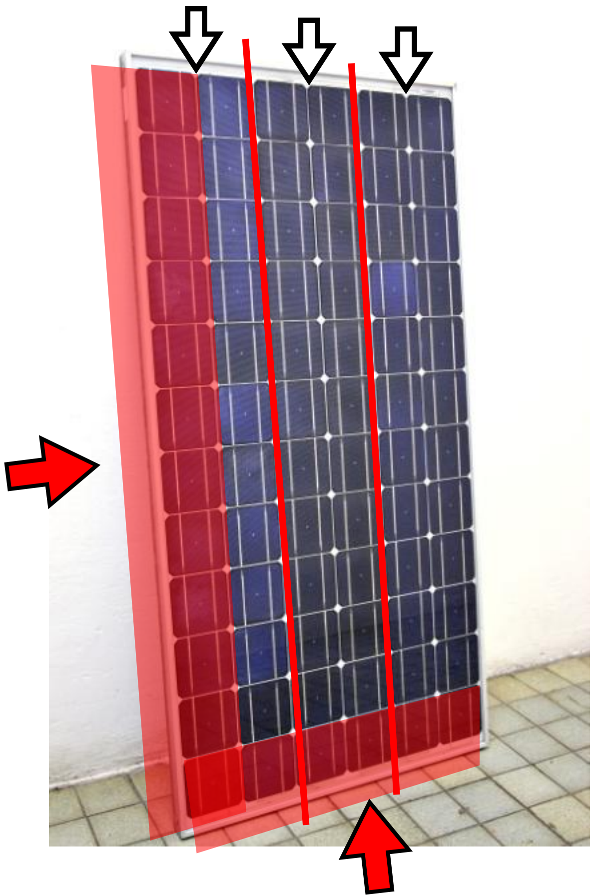


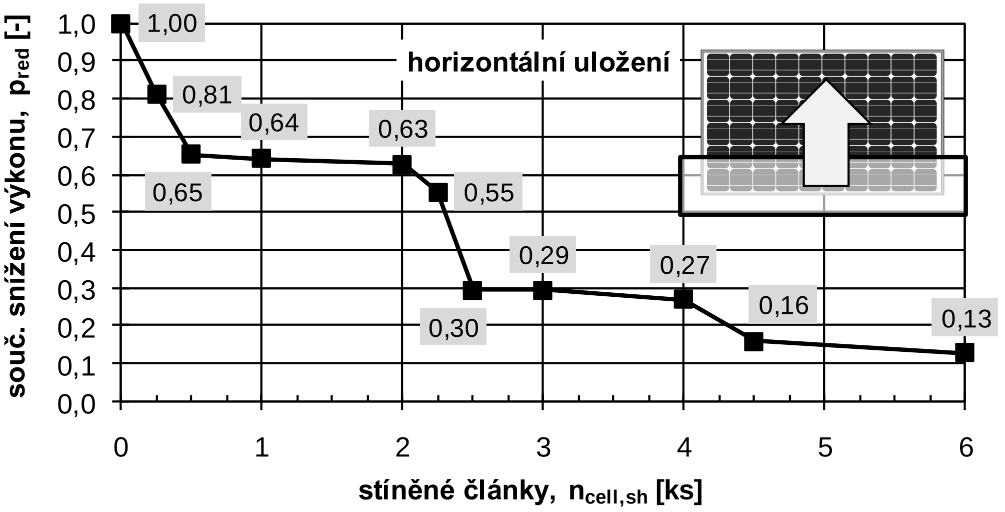
It is useful to take into account possible influence by objects in surrounding

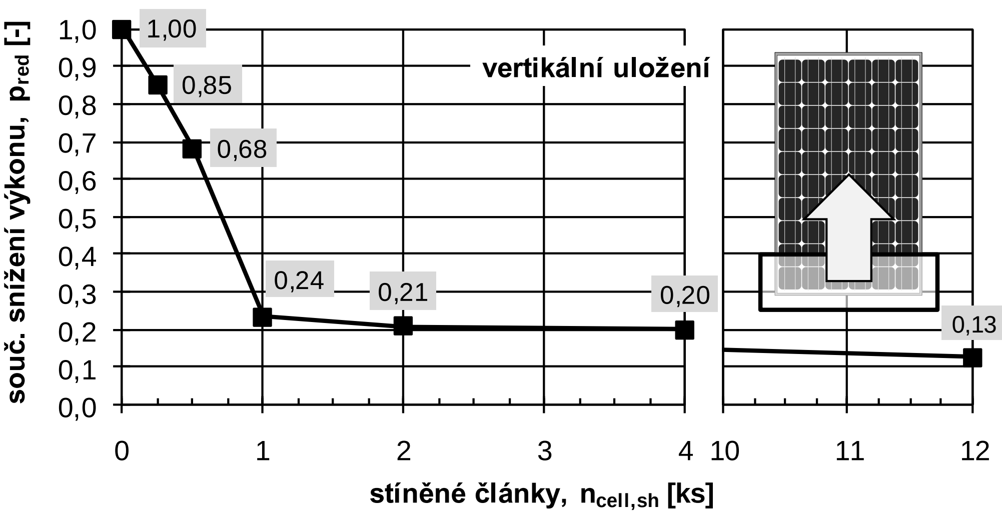
The partial shading effect

c-Si module:

- 3 bypass diods

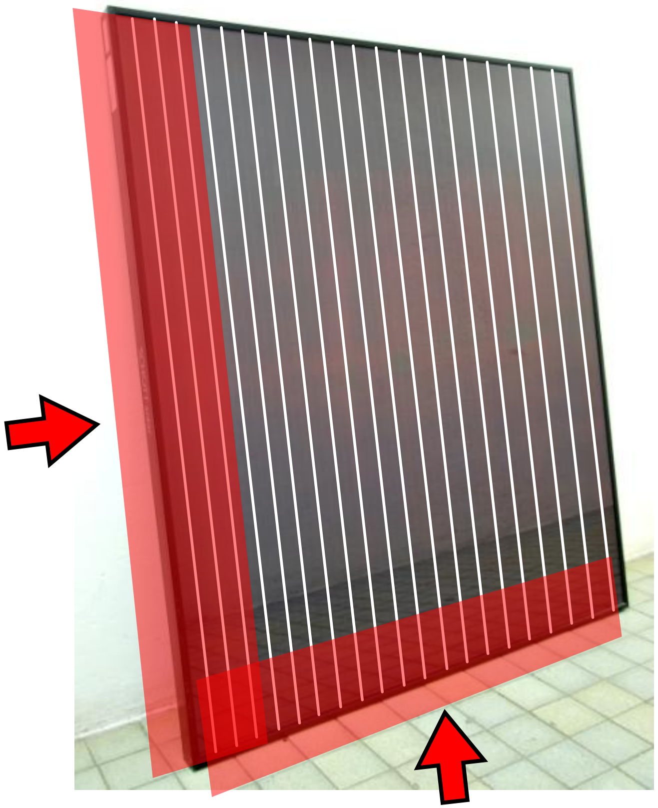


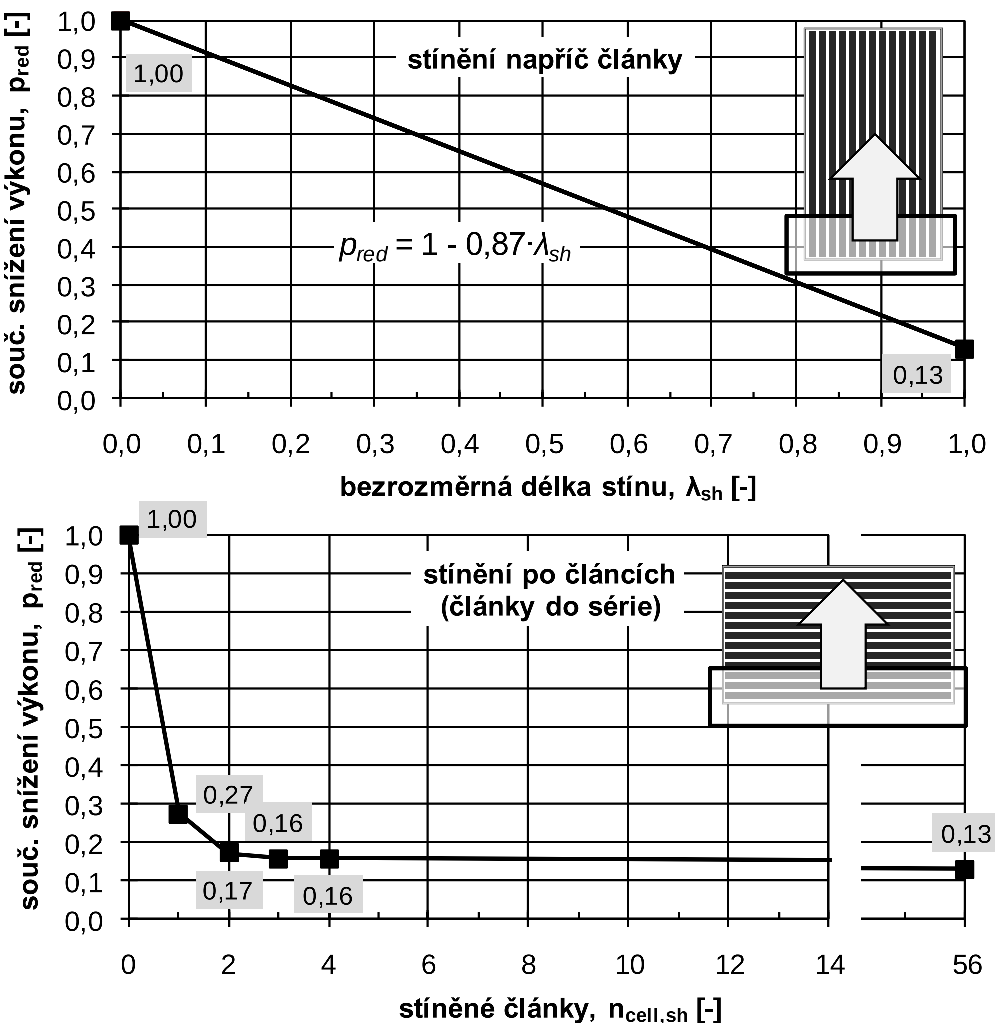




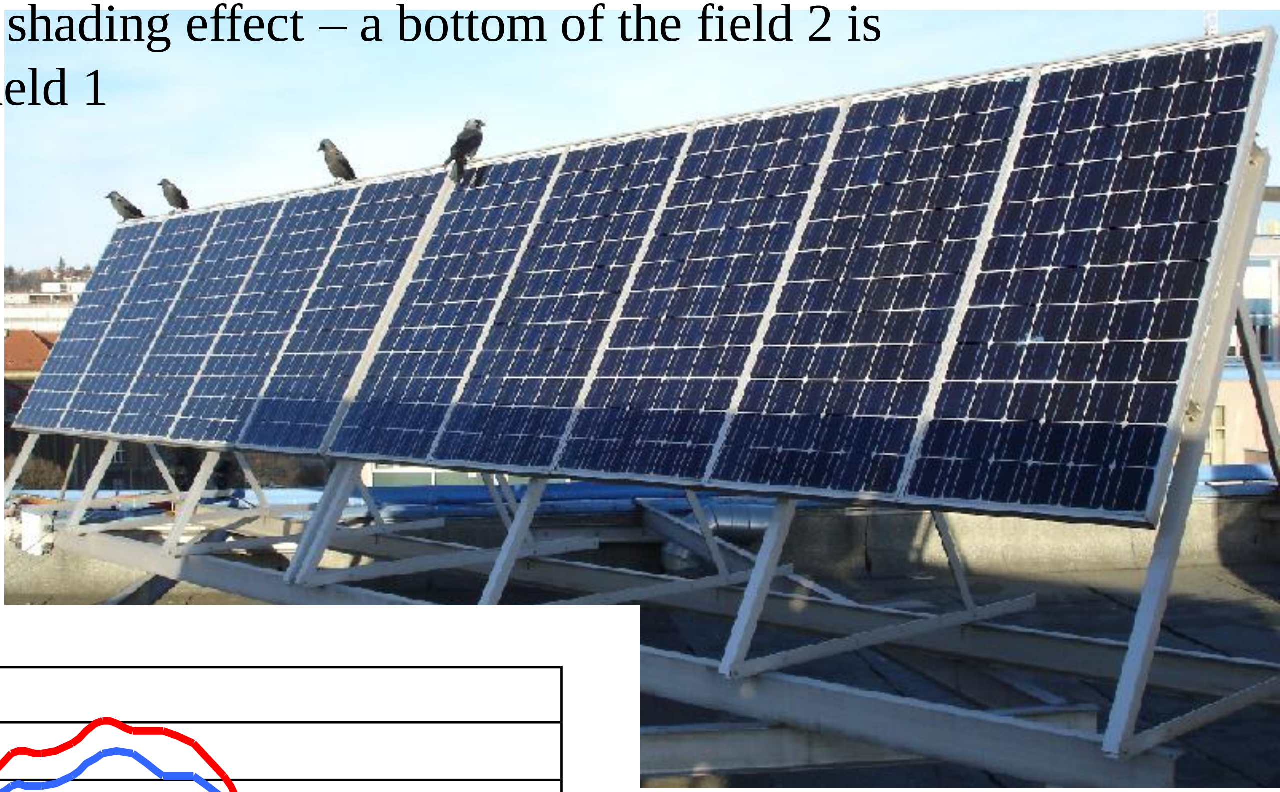
Thin film modules

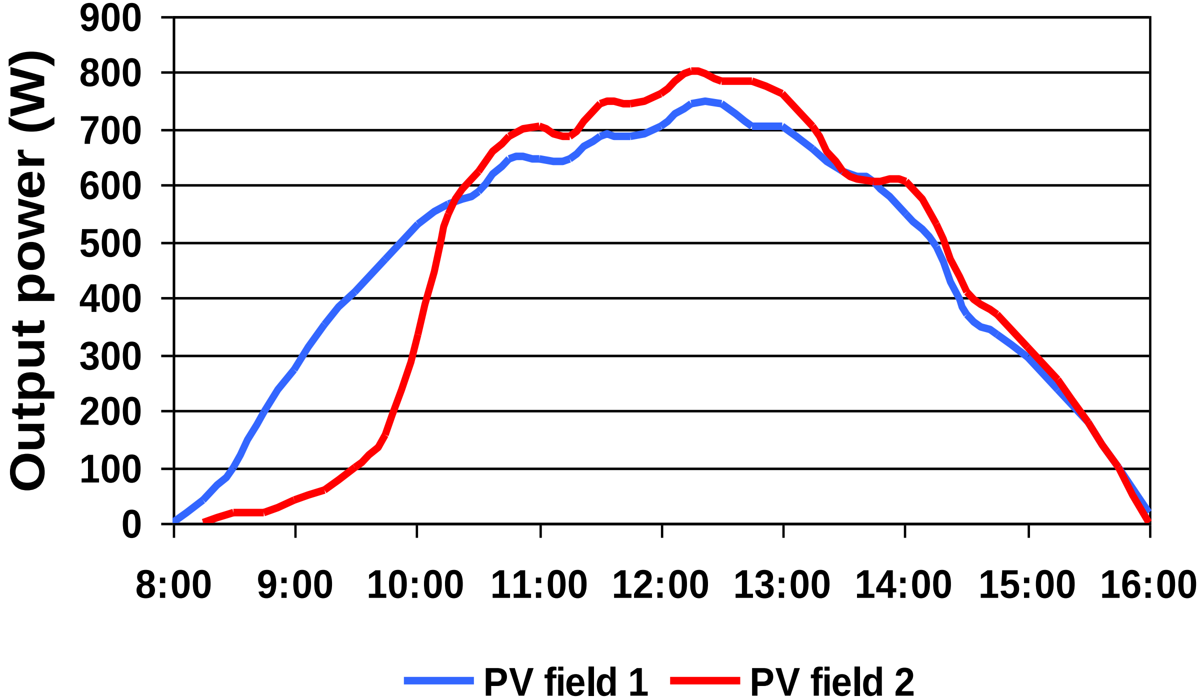
- without diodes





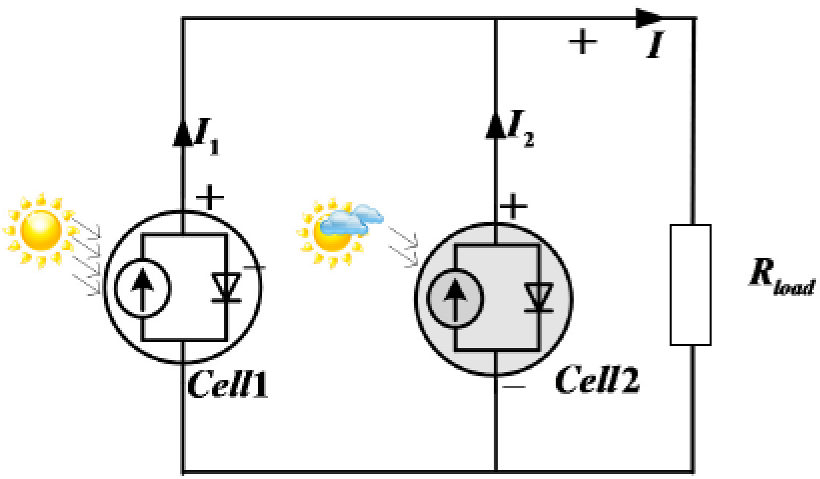
A practical example of the shading effect – a bottom of the field 2 is shaded in January by the field 1

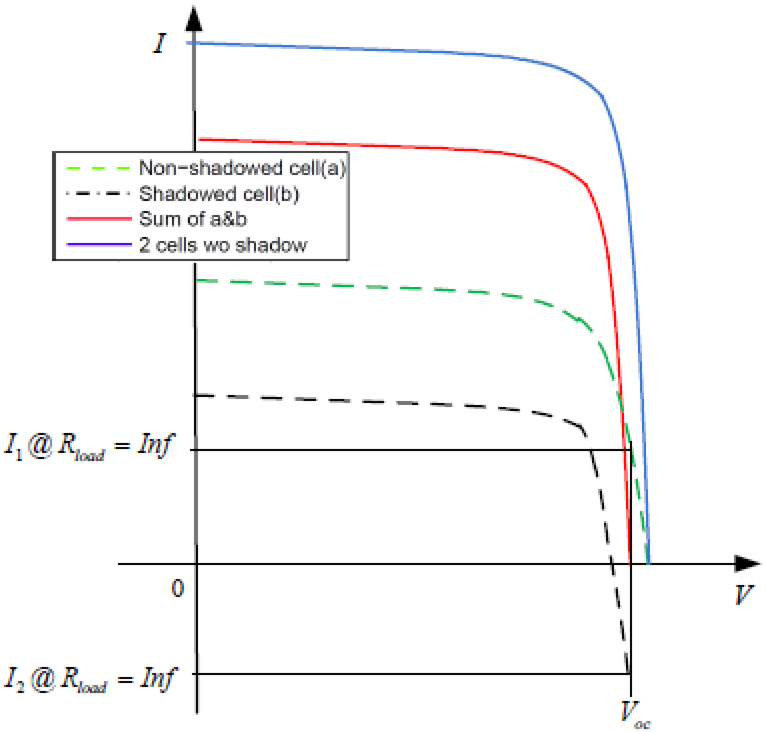




Effect of snow

Non-uniform irradiation for parallel-connected cells





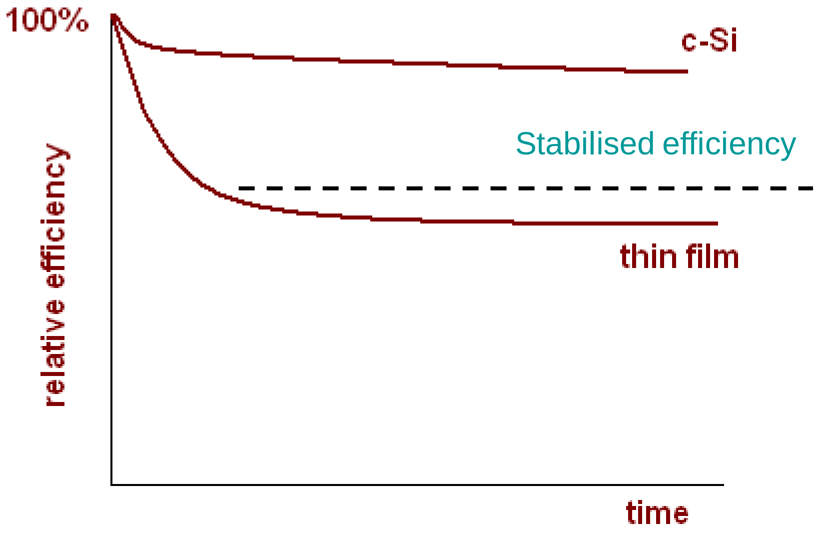
At open circuit and at light loads, the current can reverse in *Cell2*

For parallel connected PV strings this is prevented by a blocking diode

Module lifetime

Time from starting electricity production till the output shall not fall below 80% of the rated value

Ageing – degradation processes



C-Si

Decrease of glass and EVA transprarency, corrosion effects

Thin films

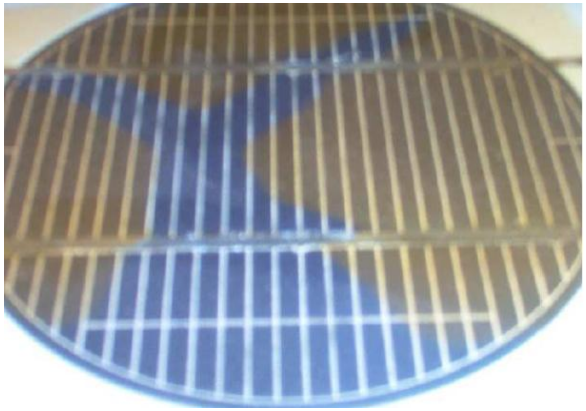
Thermo-mechanical stress
(adhesion and cohesion of interfaces)
Transparency of encapsulation, corrosion effects

Module type testing

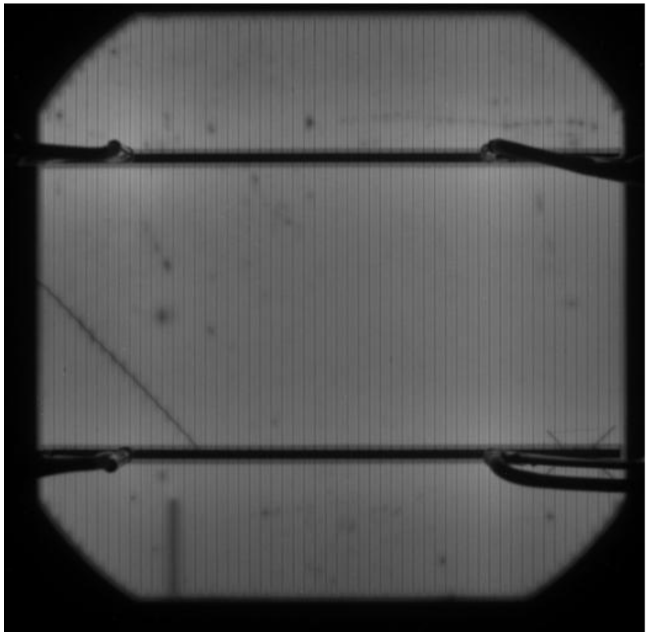
- Ultraviolet exposure using xenon lamps.
- Thermal cycling (−40◦C to 50◦C, 50 cycles) in conditioning chamber.
- Humidity freeze cycling (thermal cycling with 85% relative humidity).
- Damp heat (1000 h at 85◦C and 90% relative humidity).
- Twist test for testing resistance to torques.
- Pressure is applied to the module to test resistance to static mechanical loads.
- Hail impact test, where the module is stricken by 25 mm diameter ice balls at 23 mseg−1.
- Outdoor exposure.
- Hot spot tests, where the module is selectively shaded.

Reliability problems

- Environmental effect and aging results in a decrease of efficiency
  - a decrease of glass transparency
  - a decrease of EVA transparency (browning)
  - an increase of series resistance
  - degradation of individual layers of the cell structure



A target: increase module lifetime > 30 years

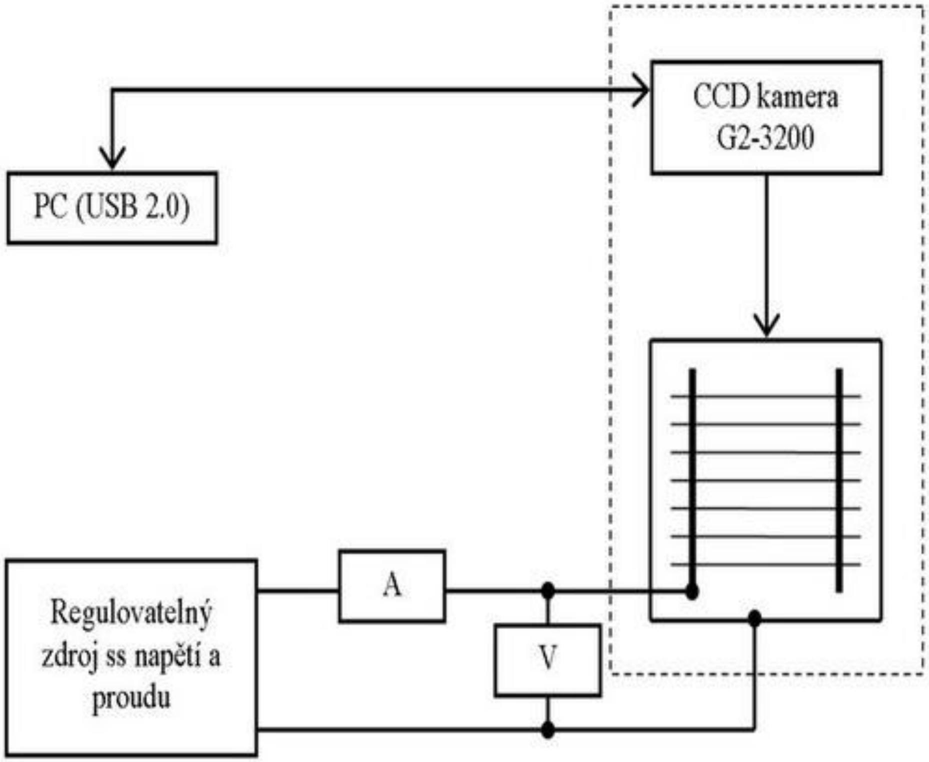


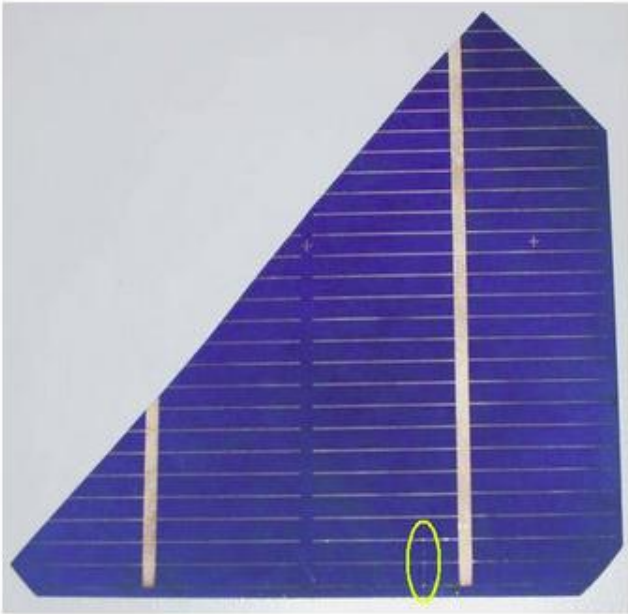
Type of failure	Possible effect on the I-V curve
Corrosion[1,2]	Increased Rs → reduced FF
Cell interconnect break [2]	Increased Rs, reduced FF, PS
Decreased transparency of covering layers	
- Soiling - Dust /Stain - Discoloration of plastic encapsulates	Reduced FF, PS Decreased peak power Decreased peak power, reduced FF, PS
Mismatches	Reduced FF, PS
Ageing of the semiconductor material	Decreased peak power, reduced FF

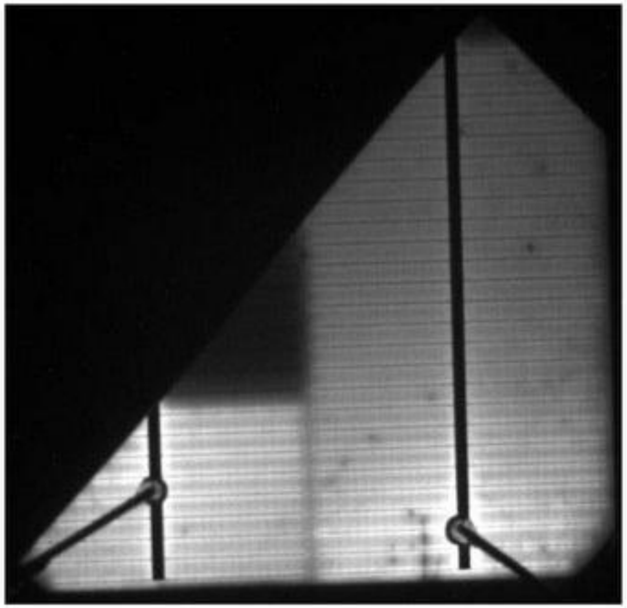
FF – Fill Factor, PS – Partial Shadow

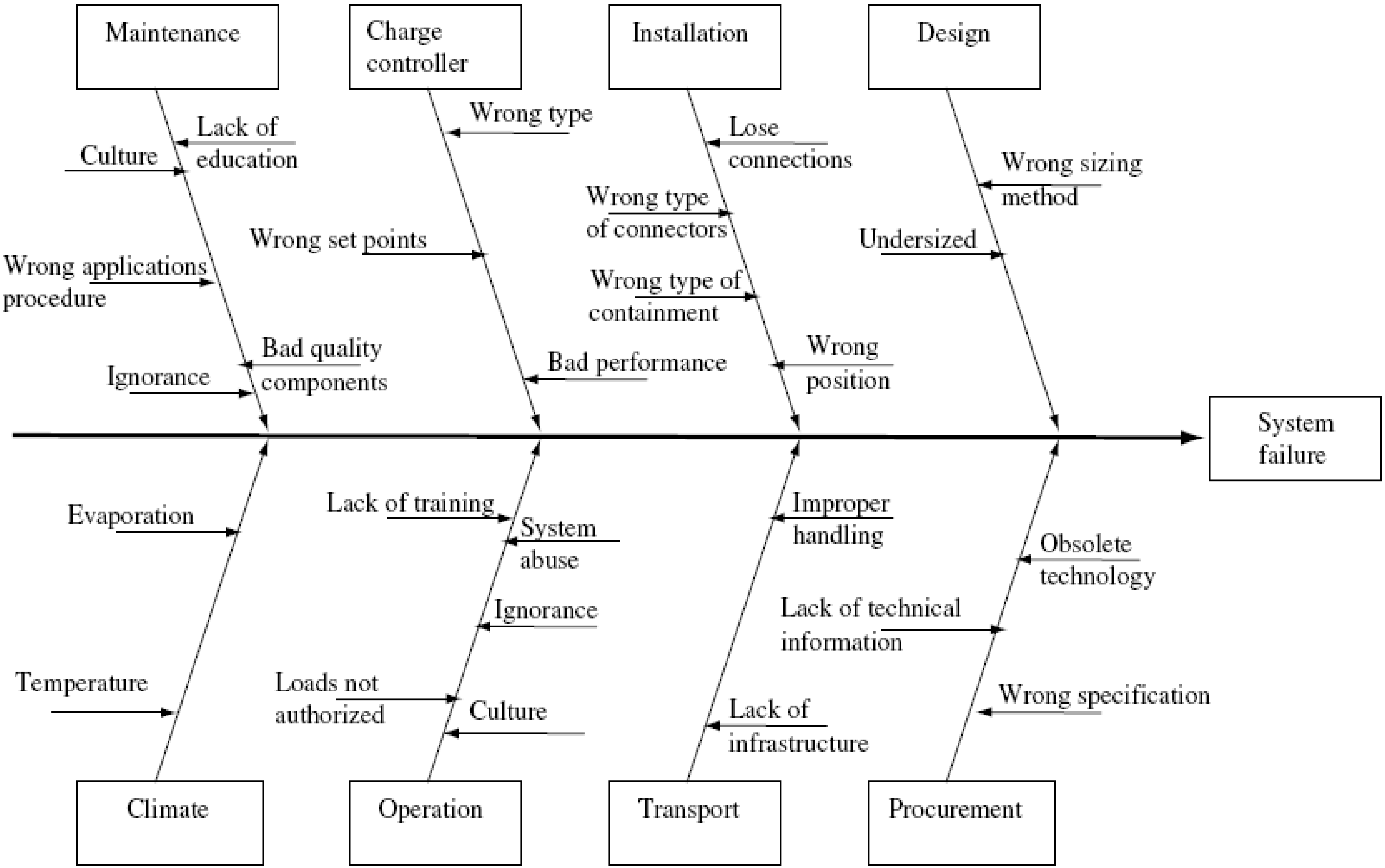
Series resistance increase is the main reason for module performance degradations

Electroluminiscence








Maintenance
Charge controller
Installation
Design
Lack of education
Culture
Wrong applications procedure
Bad quality components
Ignorance
Wrong type
Wrong set points
Bad performance
Lose connections
Wrong type of connectors
Wrong type of containment
Wrong position
Wrong sizing method
Undersized
System failure
Evaporation
Temperature
Lack of training
System abuse
Ignorance
Loads not authorized
Culture
Improper handling
Lack of infrastructure
Obsolete technology
Lack of technical information
Wrong specification
Climate
Operation
Transport
Procurement