SUPSI University of Applied Sciences and Arts of Southern Switzerland

CASE STUDY

PARTIAL SHADING INDUCED DEGRADATION

2018-2020 FIELD STUDY

Defects / Errors / Failures in strings	Quantity
Power Degradation (at STC)	96.5 %
Soiling	88.9 %
Partial shading	53.3 %
Permanent partial shading	16.7 %
Defects / Dirt in inverter	10.0 %
Broken glass	3 modules
Disconnected strings	1.4 %

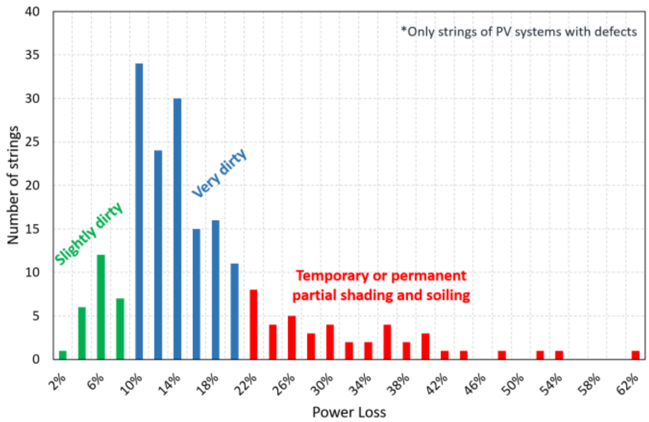

Figure 1: Percentage of strings with detected defects among 203 strings from 30 PV systems in Ticino and the corresponding reduction in maximum power.

SUPSI carried out a field study in 2018-2020 on 30 residential PV systems in Ticino, funded by the Fondo Energie Rinnovabili (FER). Although the sample size is limited, the results provide valuable qualitative insights (Figure 1). Key findings include:

- **16.7%** of the analysed systems were affected by **permanent partial shading**
- **More than 50%** experienced **temporary partial shading**
- **Defects (i.e. discolouration and glass breakage)** were observed in a small portion of strings exposed to shading

Based on field observations, three typical scenarios can be distinguished when PV modules are exposed to persistent partial shading.

Scenario-1: No Bypass Diode Activation

Instantaneous power loss only

In this case, partial shading reduces the module's power output only during the shading event. The impact is limited to a loss of energy yield, and no long-term damage to the module is expected.

Scenario-2: Bypass Diode Activation

Instantaneous power loss and progressive material degradation

Persistent shading can trigger repeated bypass diode activation, leading to recurring hot spots in the same module area/s over many years. Even if peak temperatures remain moderate, repeated thermal stress can accelerate material ageing. This mechanism typically does not pose an immediate safety risk. However, it leads to additional long-term performance degradation, beyond the instantaneous energy loss caused by shading.

A case from Switzerland illustrates this effect in an Al-BSF module exposed to persistent partial shading for more than 11 years (Figure 2). The affected area showed:

- Accelerated encapsulant degradation
- Visible discolouration
- Corrosion of solar cells detected by electroluminescence imaging.

Accelerated encapsulant degradation produces acetic acid, which contributes to cell corrosion and results in permanent module degradation.

Figure 2: (a) Rooftop PV system exposed to persistent shading for more than 11 years; (b) encapsulant discolouration; (c) increased UV fluorescence indicating accelerated degradation; (d) corrosion visible in electroluminescence imaging.

Scenario-3: Bypass Diode Failure

Material failure and potential safety risk

If the stress intensifies due to very high hot spot temperatures and frequent repetition, PV module components may fail. Possible damages with safety risks include delamination, glass breakage and bypass diode failure. Damage to a bypass diode results in a loss of its protective function. When a bypass diode fails in an open-circuit, intense local heating during shading events can pose a significant safety risk.

A case from a PV system in Switzerland illustrates this damage mechanism. Only the modules located close to a shading obstacle experienced high-risk damages (Figure 3). In these modules, bypass diodes exposed to continuous partial shading were damaged and could no longer protect the affected cell strings. As a result, continued partial shading after diode failure led to even higher hot spot temperatures, causing discolouration, delamination, glass breakage, and an increased safety risk. Although no serious incident occurred, the potential safety risk is evident.

No comparable damage was observed in the several hundred other modules within the same system that were not exposed to continuous partial shading.

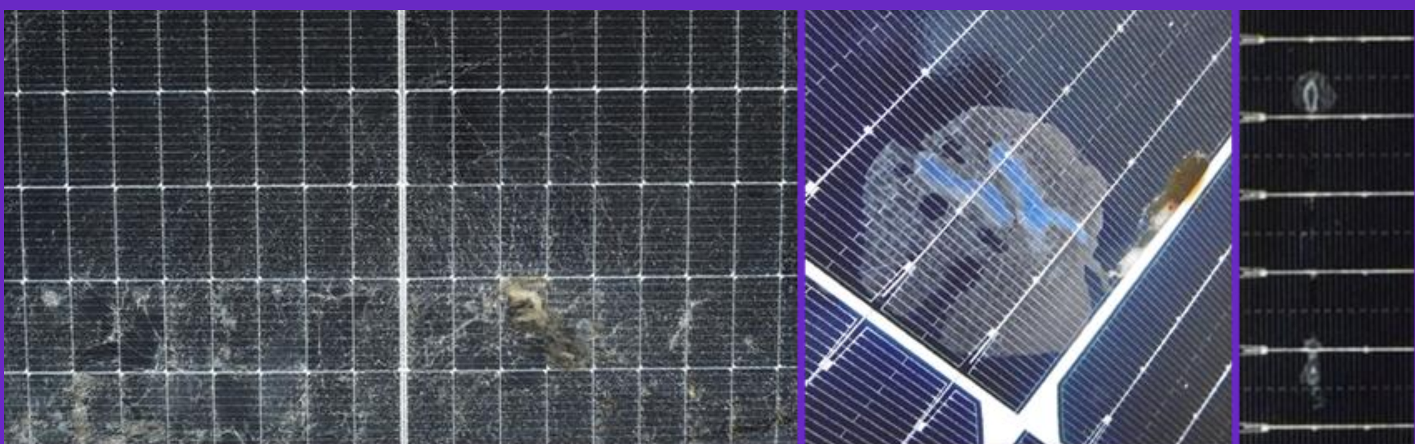

Figure 3: Visual images of three modules removed from a persistently shaded area of a PV system. Modules in non-shaded areas showed no comparable damage.

Mitigation Strategies

If large-scale deployment of PV on buildings and infrastructure is a national objective in Switzerland, optimising energy yield, minimising long-term degradation, and ensuring system safety must be addressed simultaneously.

Key mitigation strategies include:

1. **Realistic testing**
   Module and bypass diode testing under realistic operating conditions beyond current IEC standard test procedures

2. **Proper PV system design**
   Appropriate module selection, electrical system design, and module placement, with explicit consideration of nearby shading objects

3. **Operation and maintenance**
   Use of monitoring systems with suitable alarms, regular inspections, and targeted maintenance of shading-affected installations