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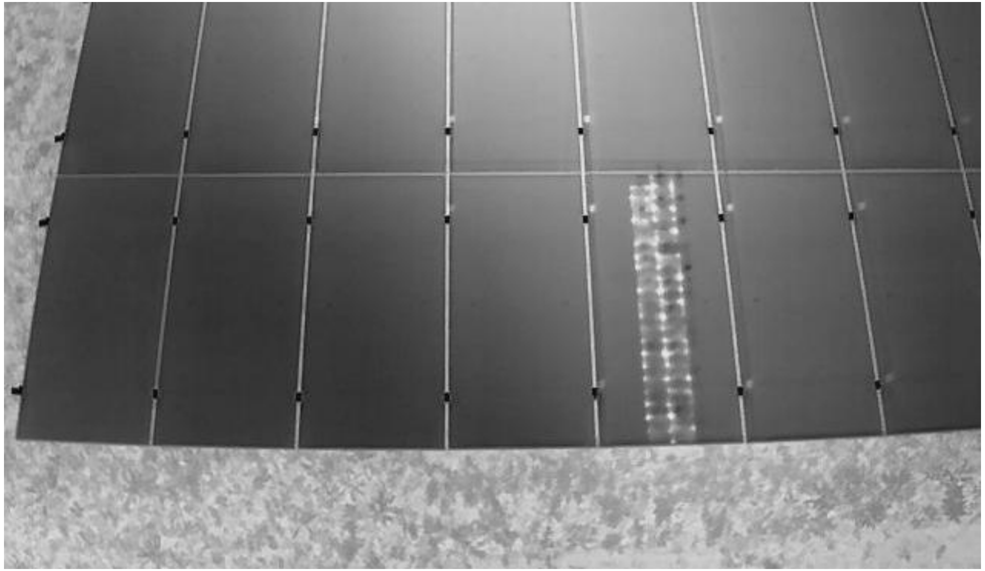

Degradation and Failure Modes in New Photovoltaic Cell and Module Technologies

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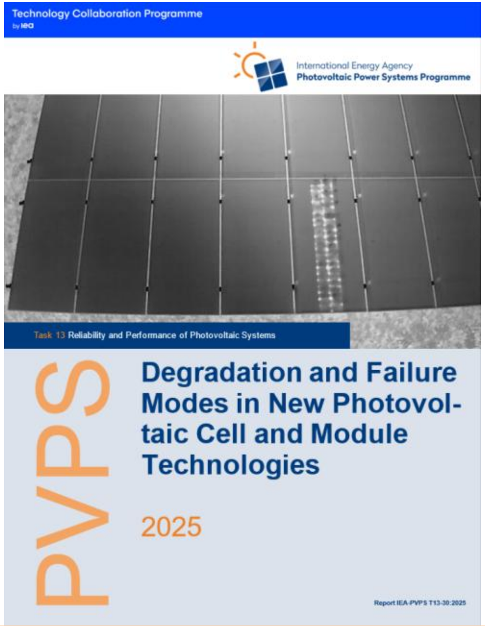
Degradation and Failure Modes in New PV Technologies

Introduction

- Literature, test results and current field experience are collected to asses weaknesses of new module technologies such as TOPCON and HJT.
- For perovskite-based PV technologies, a comprehensive literature is conducted to identify all degradation pathways that need to be adresses for reliable use in PV applications.
- If available mitigation strategies are identified.



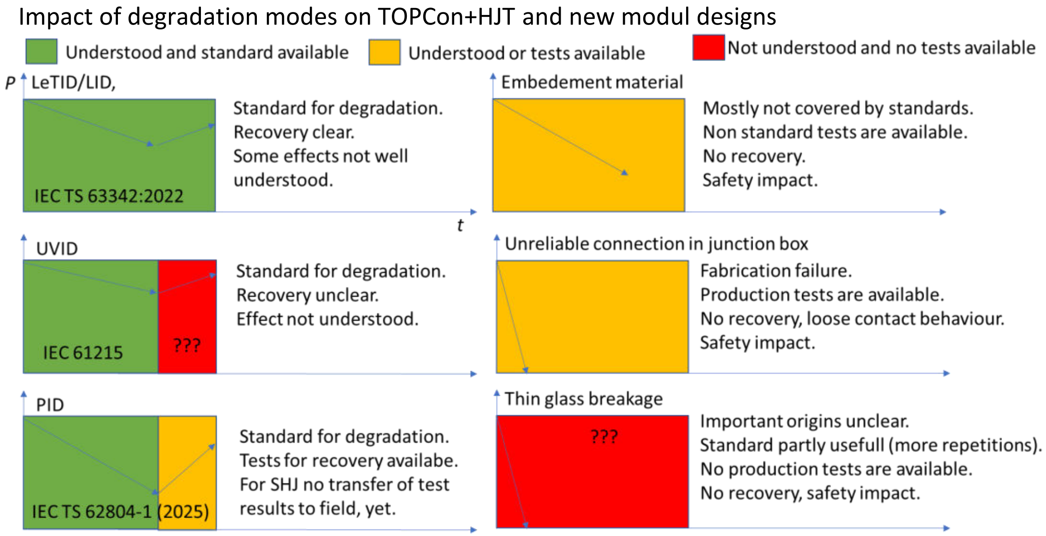
This report overviews currently know degradation modes and failures and their mitigations

Report IEA-PVPS T13-30:2025, February 2025

Degradation and Failure Modes in New PV Technologies

Most important results of literature review and practical experiences from the field

- Some primary important failure types seem to be mitigated like LID/LeTID and cell part isolation.
- Many current module types show high degradation of up to 10% after 60 kWh/m² UV dose in lab tests.
- IEC61215 tests does not test for new embedment material degradation. Additional test are needed.
- Thin glass breakage and cold solder joints are critical current failure types.



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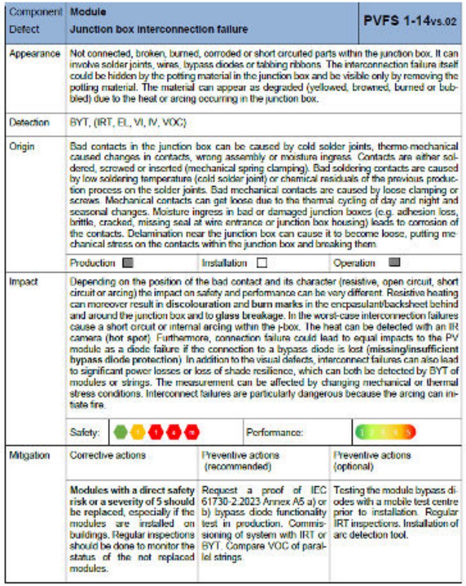
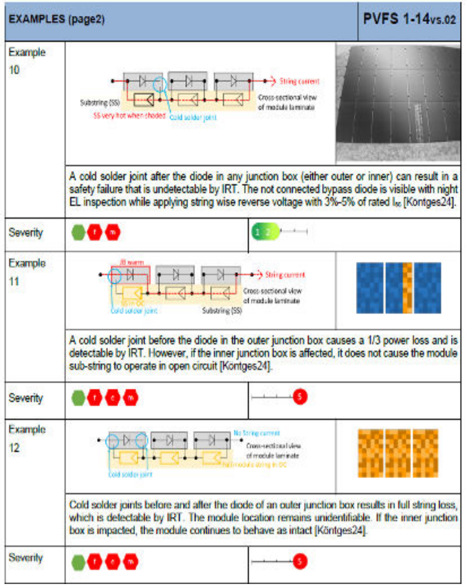
Photovoltaic Failure Fact Sheets (PVFS) 2025

Praxis and field-oriented information for PV planners, installers, investors, inspectors, consultant or insurance companies.

- COMPONENT
- DEFECT
- APPEARANCE
- DETECTION
- ORIGIN
- IMPACT
- MITIGATION
- EXAMPLES



Component Defect	Module **Junction box interconnection failure**			**PVFS 1-14vs.02**
Appearance	Not connected, broken, burned, corroded or short circuted parts within the junction box. It can involve solder joints, wires, bypass diodes or tabbing ribbons. The interconnection failure itself could be hidden by the potting material in the junction box and be visible only by removing the potting material. The material can appear as degraded (yellowed, browned, burned or bubbled) due to the heat or arcing occurring in the junction box.			
Detection	BYT, (IRT, EL, VI, IV, VOC)			
Origin	Bad contacts in the junction box can be caused by cold solder joints, thermo-mechanical caused changes in contacts, wrong assembly or moisture ingress. Contacts are either soldered, screwed or inserted (mechanical spring clamping). Bad soldering contacts are caused by low soldering temperature (cold solder joint) or chemical residuals of the previous production process on the solder joints. Bad mechanical contacts are caused by loose clamping or screws. Mechanical contacts can get loose due to the thermal cycling of day and night and seasonal changes. Moisture ingress in bad or damaged junction boxes (e.g. adhesion loss, brittle, cracked, missing seal at wire entrance or junction box housing) leads to corrosion of the contacts. Delamination near the junction box can cause it to become loose, putting mechanical stress on the contacts within the junction box and breaking them.			
	Production ■	Installation □	Operation ■	
Impact	Depending on the position of the bad contact and its character (resistive, open circuit, short circuit or arcing) the impact on safety and performance can be very different. Resistive heating can moreover result in discolouration and burn marks in the encpasulant/backsheet behind and around the junction box and to glass breakage. In the worst-case interconnection failures cause a short circuit or internal arcing within the j-box. The heat can be detected with an IR camera (hot spot). Furthermore, connection failure could lead to equal impacts to the PV module as a diode failure if the connection to a bypass diode is lost (missing/insufficient bypass diode protection). In addition to the visual defects, interconnect failures can also lead to significant power losses or loss of shade resilience, which can both be detected by BYT of modules or strings. The measurement can be affected by changing mechanical or thermal stress conditions. Interconnect failures are particularly dangerous because the arcing can initiate fire.			
	Safety:		Performance:	
Mitigation	Corrective actions	Preventive actions (recommended)	Preventive actions (optional)	
	Modules with a direct safety risk or a severity of 5 should be replaced, especially if the modules are installed on buildings. Regular inspections should be done to monitor the status of the not replaced modules.	Request a proof of IEC 61730-2:2023 Annex A5 a) or b) bypass diode functionality test in production. Commissioning of system with IRT or BYT. Compare VOC of parallel strings.	Testing the module bypass diodes with a mobile test centre prior to installation. Regular IRT inspections. Installation of arc detection tool.	



EXAMPLES (page2)		**PVFS 1-14vs.02**
Example 10	A cold solder joint after the diode in any junction box (either outer or inner) can result in a safety failure that is undetectable by IRT. The not connected bypass diode is visible with night EL inspection while applying string wise reverse voltage with 3%-5% of rated I_{sc} [Kontges24].	
Severity		
Example 11	A cold solder joint before the diode in the outer junction box causes a 1/3 power loss and is detectable by IRT. However, if the inner junction box is affected, it does not cause the module sub-string to operate in open circuit [Kontges24].	
Severity		
Example 12	Cold solder joints before and after the diode of an outer junction box results in full string loss, which is detectable by IRT. The module location remains unidentifiable. If the inner junction box is impacted, the module continues to behave as intact [Köntges24].	
Severity		

The original PV failure fact sheets (PVFS 2021) were reviewed to include failures occurring in new module technologies and its impact in the field:

- *Spontaneous thin glass breakage*
- *PID-p in bifacial modules*
- *Cold solder joints in new generation junction boxes*
- *Cracking and delamination in new backsheet materials*
- *Cell-cracking in MBB/multi-wire or shingled modules*

PVPS

The PVFS introduces main failures, how to detect and mitigate them, and provides information on their impact on safety and power generation, together with practical examples.

Degradation and Failure Modes in New PV Technologies

- **Impact of Innovation on Degradation**: Cell cracking issues are mitigated by multi-wire technology. LeTID is addressed by gallium-doped wafers and improved manufacturing.
- **Potential-Induced Degradation** mechanisms can be reduced through targeted tests and adjustments at cell, module, and system level. UV irradiation during testing minimize degradation in specific cell types like TOPCon and will be added in upcoming tests.
- **UV-Induced Degradation** occurs in some PV modules, but is manageable by using UV-stable designs and encapsulation materials. However, further research is required.
- **Encapsulation Material Challenges**: The degradation of polymer materials is still a major problem. New tests combining stresses like UV, humidity, and temperature are required.
- **Thin Glass Durability**: Thin glass in modern modules has shown in some cases high breakage rates, necessitating multiple-module testing under real installation conditions.
- **Junction Box Reliability**: Faulty bypass diode connections pose a safety and performance risk. It is recommended to implement tests during production and in affected installations.
- **Perovskite based PV modules:** There are numerous reliability issues for perovskite-based PV module technologies in literature. Many possible solutions, but all challenges must be solved at once.