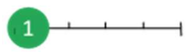
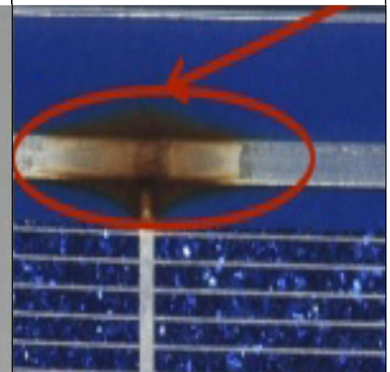
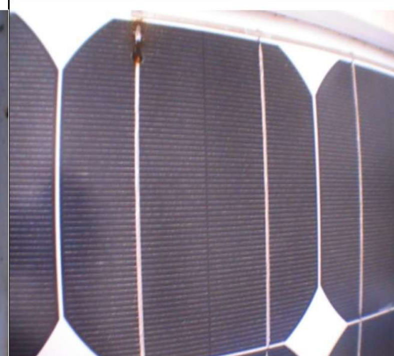
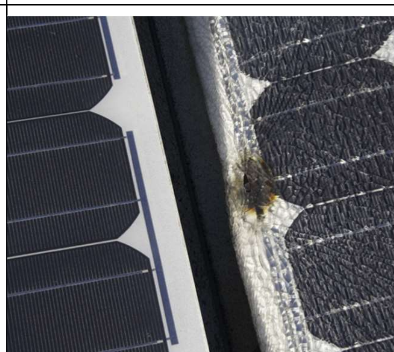
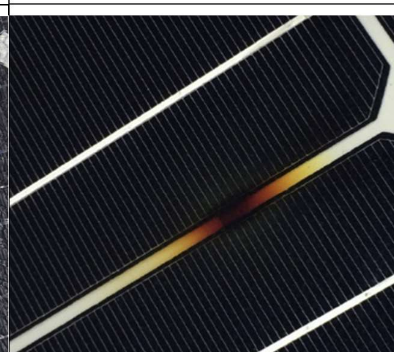
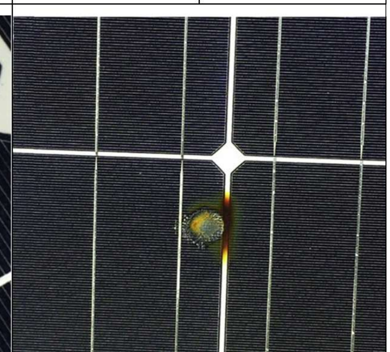
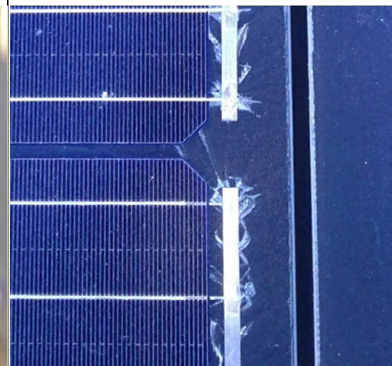
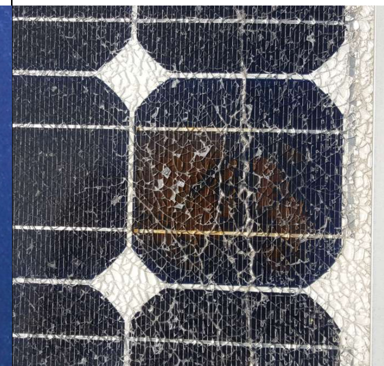
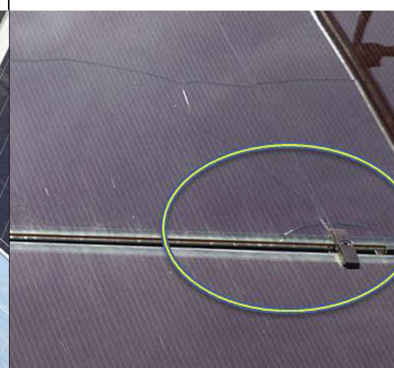
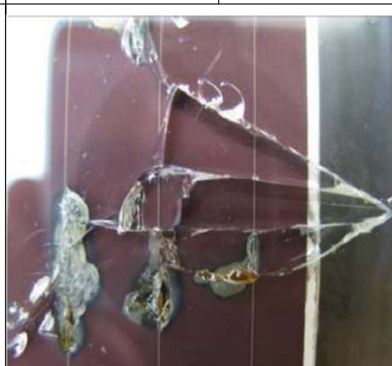
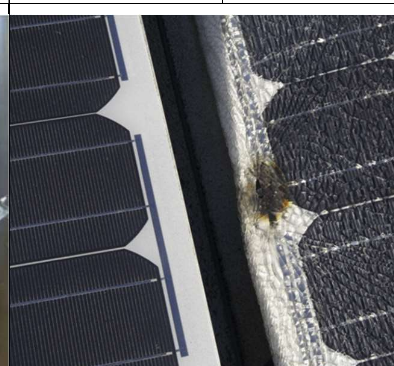
<table>
<tr><td>Component
Defect</td><td colspan="4">Module
Backsheet chalking (whitening)</td><td colspan="2">PVFS 1-6vs.01</td></tr>
<tr><td>Appearance</td><td colspan="6">White powder is detectable on the external surface of the backsheet. It can be seen by passing a finger over the backsheet. It can be removed. The backsheet has usually a rough or dull appearance.</td></tr>
<tr><td>Detection</td><td colspan="6">VI</td></tr>
<tr><td rowspan="2">Origin</td><td colspan="6">Chalking is caused by the photothermal degradation of the polymers in the outer backsheet layer containing inorganic pigments. For example, TiO_2 pigments are often used in the outer layers as UV blocker.</td></tr>
<tr><td colspan="2">Production ■</td><td colspan="2">Installation ☐</td><td colspan="2">Operation ■</td></tr>
<tr><td rowspan="2">Impact</td><td colspan="6">Chalking does not affect module safety or performance on first sight, but it can be a sign for an ongoing degradation of the backsheet and a precursor for severe backsheet cracking. Due to the degradation-induced reduction of UV protection, more serious failures, such as back-sheet cracking and insulation failures can occur. Enhanced moisture diffusion into the en-capsulant/active PV-parts can lead to corrosion of cells and connectors, having a negative impact also on the performance.</td></tr>
<tr><td>Safety:</td><td colspan="2"></td><td>Performance:</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Mitigation</td><td colspan="2">Corrective actions</td><td colspan="2">Preventive actions (recommended)</td><td colspan="2">Preventive actions (optional)</td></tr>
<tr><td colspan="2">Regular inspections should be done to monitor the progress of the observed failure. Ground fault detection by inverter or other devices at all time.</td><td colspan="2">Check validity of IEC 61215 certification and BOM.</td><td colspan="2">Regular system inspections.</td></tr>
</table>

EXAMPLES (page1)					**PVFS 1-6vs.01**	
Examples 1-2						
	Finger with white powder. [TUV Rheinland]		Fingerprint on a module with chalking. [TUV Rheinland]			
Severity						

Component Defect	**Module** **Burn marks**		**PVFS 1-7vs.01**
Appearance	Burn marks are visible with the naked eye as burnt, blackened area/s. The burn mark may lead to bubbling or melting of the polymeric encapsulant, and/or glass breakage or a hole in the backsheet. Burn marks on the backheet may be not visible from the front requiring an inspection with an IR camera if the back of the module is not accessible. They may however not be visible by IR inspection in case no further or ongoing heating occurs.		
Detection	VI, IRT, (EL)		
Origin	The defect is associated with parts of the module that became very hot because of production errors (e.g weak solder bonds, ribbon breakage, incomplete cell edge isolation, alignment errors, metal particles) and/or transportation/handling errors (e.g, **cracked cells, damaged back-sheet**) in combination with one or more operational factors (e.g. shadowing, **open circuited bypass diodes**, reverse current flows). Physical stress during PV module transportation, heavy snow loads, a lightning strike, thermal cycling, and/or **hot spots** by partial cell shading during long-term PV system operation forces mechanical weak(ended) cell/connection parts to break. Burn marks occur for example when a reverse current flow causes heating that further localizes the current flow, leading to a thermal runaway effect and the associated burn mark.		
	Production ■	Installation ■	Operation ■
Impact	Burn marks on interconnections are often associated with power loss, but if redundant electrical interconnections are provided, a failed solder bond may have negligible effect on the power output. If all solder bonds for one cell break, then the current flow in that string is completely blocked and an electric arc can result if the current cannot be bypassed by the bypass diode and the system operates at high voltage. Performance, reliability and safety are likely to be severely compromised. Such an arc can cause a fire if there happen to be flammable material around. If there is a question about whether the existence of the burn mark requires replacement of the module, an infrared image under illuminated and/or partially shaded conditions will quickly identify whether the area is continuing to be hot and/or whether current flow has stopped in that part of the circuit. Temperature difference between neighbouring cells should not be over 30 K. At this stage safety risk may still be not so high because the temperature of this hot spot cell does not increase to more than around 100 °C. Also edge **isolation faults** on the solar cell level are under normal conditions not problematic, but when the bypass diode is in open-circuit, the current is driven in reverse through the shunts of the solar cells and burns the encapsulation.		
	Safety:	f e m f e m	Performance: 1 2 3 4 5
Mitigation	Corrective actions	Preventive actions (recommended)	Preventive actions (optional)
	Modules with a direct safety risk or a severity of 5 should be replaced. Regular inspections should be done to monitor the status of the not replaced modules.	Visual inspection before installation, commissioning of system with IRT.	Regular system inspections.

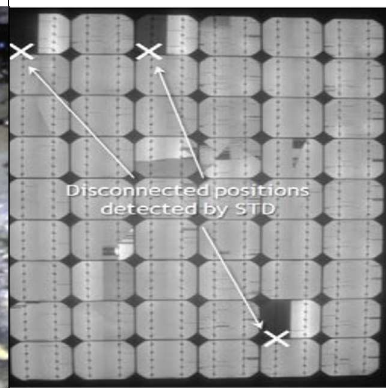
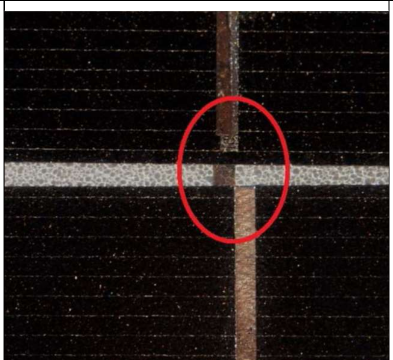
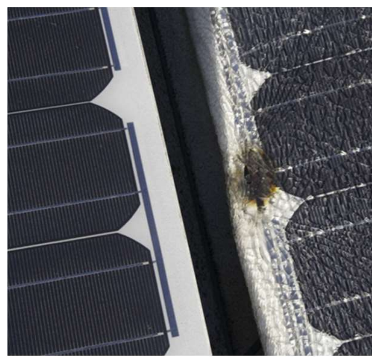
EXAMPLES (page1)			**PVFS 1-7vs.01**
Examples 1-3			
	Burn mark at the backsheet with cracked backsheet. [Sinclair17]	Burn marks at the backsheet due to heating along a busbar. [Köntges14]	Burn mark associated with overheating along the metallic interconnection (without back-sheet damage). [Köntges14]
Severity	f e m — 5	f e m — 3 4 5	f e m — 2 3
Examples 4-6			
	Front and back side view of burn marks caused by open-circuited bypass diodes and current mismatch conditions (due to shading or cracked cells). [Köntges14]		Burn marks caused by defect bypass diodes or an interconnect failure in the junc. box. [Köntges14]
Severity	f e m	3 4 5	f e m — 3 4 5
Examples 7-9			
	Burn mark with broken glass caused by poor bussing ribbon soldering. [Yang19] (s. also PVFS 1-8 and PVFS 1-8)	Burn mark due to intrinsic shunting caused by error in manufacturing process. [Yang19]	Burn mark due to intrinsic shunting caused by error in manufacturing process. [Yang19]
Severity	f e m — 3 4 5	f e m — 1 2 3	f e m — 1 2 3

<table>
<tr><td>Component
Defect</td><td colspan="4">Module
Glass breakage</td><td colspan="2">PVFS 1-8vs.01</td></tr>
<tr><td>Appearance</td><td colspan="6">Glass is cracked locally or over the full area of the module. Glass breakage looks different depending on the type of glass and the origin of the glass breakage. Tempered glass or heat-treated float glass will shatter into small pieces, whereas annealed glass breaks into big pieces. Heat-treated glass stays in between.</td></tr>
<tr><td>Detection</td><td colspan="6">VI, IRT</td></tr>
<tr><td rowspan="2">Origin</td><td colspan="6">Glass breakages of the front glass can be caused by heavy impacts such as hail or stones or other extreme mechanical stress onto the module frame due to external stresses or bad mounting. High temperatures (hot-spot or arc) can also break the glass. Annealed glass breaks also due thermal gradients or stress induced by the lamination process or cleaning of the modules. A relatively often seen failure in the field is glass breakage of frameless PV modules caused by the clamps. Glass/glass modules are more sensitive to glass breakage. The origin of the failure is, on the one hand, at the planning and installation stage either (a) poor clamp geometry for the module, e.g. sharp edges, (b) too short and too narrow clamps or (c) the positions, kind or number of the clamps on the module not being chosen in accordance with the manufacturer's manual. The second origin which induces glass breakage could be excessively-tightened screws during the mounting phase or badly-positioned clamps. The glass of some PV modules may also break due to vibrations and shocks occurring during transportation or handling. Another reason for glass breakage comes from impact stresses on the glass edge. Sometimes vandalism or animal damage happens, the animals like goats like to climb on the PV modules, and birds may drop stone or other objects from the sky.</td></tr>
<tr><td colspan="2">Production ■</td><td colspan="2">Installation ■</td><td colspan="2">Operation ■</td></tr>
<tr><td rowspan="2">Impact</td><td colspan="6">Module mechanical integrity is compromised when the glass is broken. Over time glass breakage leads to loss of performance due to cell and electrical circuit corrosion caused by the penetration of oxygen and water vapour into the PV module. Shattering of tempered glass usually also breaks the cells reducing the power of the module and increasing the risk of hot spots. Mechanical and electrical safety is thus compromised. Firstly, the insulation of the modules is no longer guaranteed, in particular in wet conditions. Secondly, glass breakage causes hot spots, which lead to overheating of the module. A module with a completely broken glass lead to current and power reductions in the whole string.</td></tr>
<tr><td>Safety:</td><td colspan="2">f e m f e m</td><td>Performance:</td><td colspan="2">1 2 3 4 5</td></tr>
<tr><td rowspan="2">Mitigation</td><td colspan="2">Corrective actions</td><td colspan="2">Preventive actions (recommended)</td><td colspan="2">Preventive actions (optional)</td></tr>
<tr><td colspan="2">All damaged modules have to be replaced.</td><td colspan="2">Adequate transport procedures, installation and cleaning by trained personal, in case of higher snow or hail loads use of certified modules.</td><td colspan="2">Regular system inspections.</td></tr>
</table>

EXAMPLES (page1)			**PVFS 1-8vs.01**
Examples 1-3			
	Chipped glass at the corner. [Packard12]	Glass breakage along the string interconnect ribbons due to weak manufacturing process. [SUPSI]	Glass breakage of tempered glass induced by a hot-spot. [SUPSI]
Severity	m — 1	f m e m — 2 3	f e m — 3 4 5
Examples 4-6			
	Glass breakage caused by too tight screws. [Köntges14] (see also PVFS 3-1)	Glass breakage caused due to poor clamp design. [Köntges14]	Glass breakage caused due to poor clamp design. [Köntges17] (see also PVFS 3-1)
Severity	f m e m — 2 3 4	f m e m — 2 3 4	f m e m — 2 3 4
Examples 7-9			
	Glass breakage through high temperature gradient and not tempered glass. [Köntges14]	Glass breakage of tempered glass induced by burn mark. [Köntges17] (see also PVFS 1-7 and PVFS 1-9)	Breakage of tempered glass. [Köntges17]
Severity	f e m — 3 4 5	f e m — 3 4 5	f e m — 3 4 5

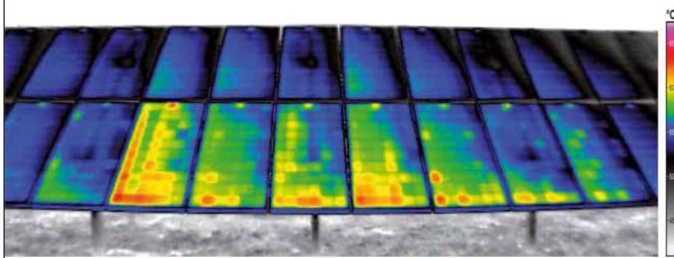
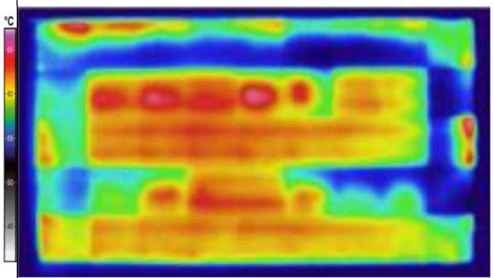
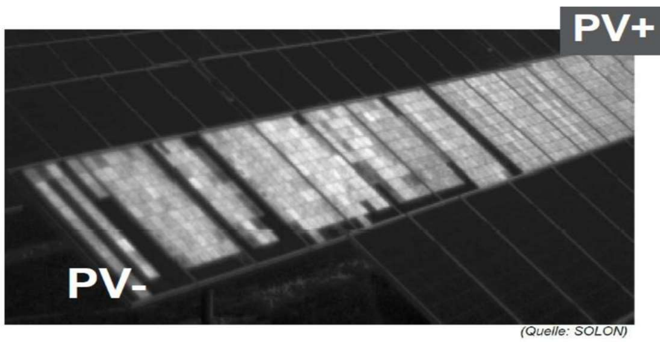
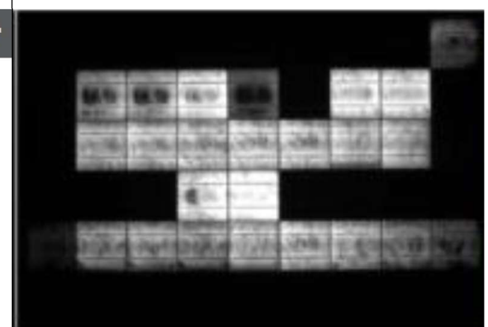
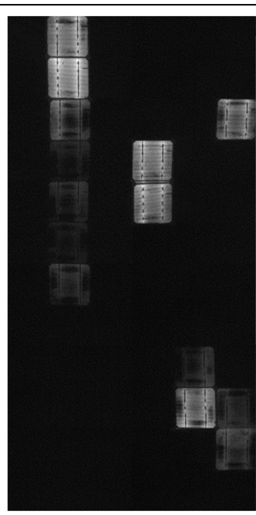
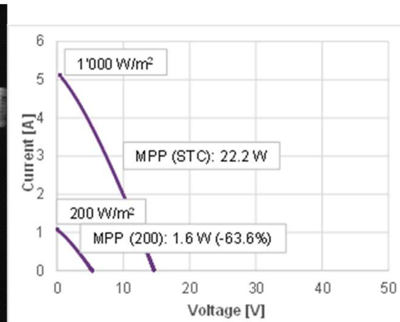
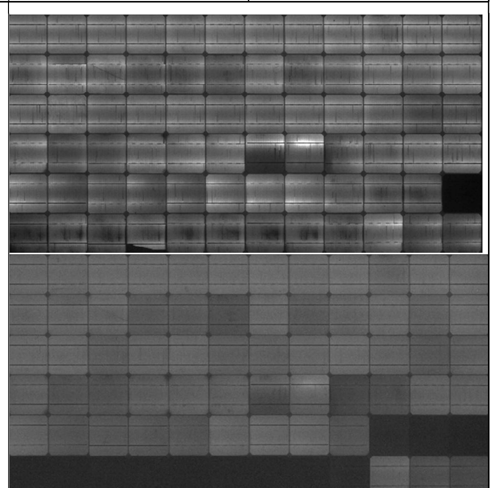
EXAMPLES (page2)			PVFS 1-8vs.01
Examples 10-12			
	Direct lightning stroke. [Könt-ges16]	Impact damage caused by a heavy object. [SUPSI]	Hail damage. [SUPSI]
Severity	f e m · 5	f e m · 5	f e m · 5

<table>
<tr><td>Component
Defect</td><td colspan="3">Module
Cell interconnection failure</td><td>PVFS 1-9vs.01</td></tr>
<tr><td>Appearance</td><td colspan="4">Weak or broken cell or string interconnection are not easy to see by the naked eye. The failure can be identified as dark region in the electroluminescence image where the failed interconnect would otherwise be collecting carriers or as a hot spot in the infrared image. In a progressed stage burn marks and glass breakage can occur.</td></tr>
<tr><td>Detection</td><td colspan="4">EL, IRT, STM, (VI)</td></tr>
<tr><td rowspan="2">Origin</td><td colspan="4">Typically, it is caused by the manufacturing process (e.g. poor soldering, misplacement of ribbons, too intense deformation of the ribbon kink, narrow distance between the cells) followed by thermomechanical stress or repetitive wind load caused by the outdoor operating environment. Electrochemical corrosion can be another cause for the degradation of interconnections.</td></tr>
<tr><td>Production ■</td><td colspan="2">Installation □</td><td>Operation ■</td></tr>
<tr><td rowspan="2">Impact</td><td colspan="4">Poor interconnections (soldering bonds) lead to an increase of contact resistance, higher power dissipation and localized heating. Broken connections are often associated with power loss, but if redundant electrical interconnections are available, a failed connection may have negligible effect on the power output. Safety risk may be not so high until the temperature of the induced hot spot does not increase to more than around 100 °C. If all busbars of a cell are interrupted, then the current flow in that string is completely blocked and an electric arc can result if the current is not bypassed by the bypass diode and the system operates at high voltage. The safety risk depends on the durability of this bypass diode. A bypass diode, which is continuously active over days can be damaged and pass into open-circuit or short circuit state. As a result of an open circuited diode, the current goes through the failed cell string and generates heat at the disconnected position. Very high temperatures or an electric arc and may cause fire, open electrical conducting parts to the user and destroy the mechanical integrity of the module.</td></tr>
<tr><td>Safety:</td><td>f e m f e m</td><td>Performance:</td><td>1 2 3 4 5</td></tr>
<tr><td rowspan="2">Mitigation</td><td>Corrective actions</td><td colspan="2">Preventive actions (recommended)</td><td>Preventive actions (optional)</td></tr>
<tr><td>Modules with a direct safety risk or a severity of 5 should be replaced. Regular inspections should be done to monitor the status of the not replaced modules.</td><td colspan="2">Check validity of IEC 61215 certification and BOM.</td><td>Regular system inspections.</td></tr>
</table>

EXAMPLES (page1)			PVFS 1-9vs.01
Examples 1-3			
	Zoom of a broken cell interconnect. [Yang19]	EL image of a module with 3 cells with disconnected inter-connect ribbons. [Köntges14]	Disconnected cell interconnect with delamination. [Köntges17]
Severity	f e / 2 3 4	f e / 2 3 4	f e / 2 3 4
Examples 4-6			
	Dislocation of interconnection ribbon. [Sinclair17]	Poor soldering of string inter-connect leading to burn mark and broken glass. [Yang19] (see also PVFS 1-7 and PVFS 1-8)	Mirco arc which occur if the conductive glue on the string inter-connect has an insufficient contact. [Köntges14]
Severity	f e / 1 2	f e m / 3 4 5	f e / 2 3 4

<table>
<tr><td>Component
Defect</td><td colspan="3">Module
Potential induced degradation (PID) (page1)</td><td>PVFS 1-10vs.01</td></tr>
<tr><td>Appearance</td><td colspan="4">A potential induced degradation (PID) is not directly visible by eye. It is recognisable as an overtime increasing power loss, which is easily observable only a few years after installation. Infrared thermography (IRT) imaging of operational PV modules in the direct sunlight is the most straightforward method for getting the evidence of PID degradation. Typical PID IRT patterns (warmer cells close to the bottom frame or patchwork patterns) and PV modules positioned close to one of the poles of the module string are strong indications for PID. The most efficient, but more complex and expensive detection method for PID is to take EL images. When taken at 1/10 of the rated current it can detect PID also in an early stage, before a power loss can be noticed. It's because in the early stage, the PID degradation is more pronounced at low light conditions. To quantify the performance loss, I-V measurements have to be performed on the affected string and/or modules. In an advanced stage secondary induced failures like hot-spot's, yellowing and/or corrosion can be sometimes observed.</td></tr>
<tr><td>Detection</td><td colspan="4">IV, EL, IRT, (MON)</td></tr>
<tr><td rowspan="2">Origin</td><td colspan="4">PID is a degradation mode induced by a high voltage stress with respect to ground. The occurrence of this failure depends on the magnitude of the voltage (number of serially connected PV modules per string) and the polarity of the electrical field build-up between the framing/glass surface and the solar cells. The last depends on the inverter typology (transformer), the grounding concept and cell technology. Modules with p-type cells degrade in negative polarity strings whereas modules with n-type cells in strings with positive polarity. PID degradation is more pronounced the higher the potential to which a single cell within a module or string is subjected. The PID effect is therefore stronger in cells that are located at the edges of the module (close to frame) and to the bottom of a string with an increase towards one end of the string. The degradation is further accelerated by temperature, humidity, rain (surface wetting), condensation and soiling. Two different types of PID are known for crystalline silicon modules: PID-p (polarization) and PID-s (shunting). The PID-p was observed for the first time in back contact cells within Sunpower modules. PID-p is caused by the build-up of negative surface charges on the cells, which results in a current loss. The PID-s is induced by leakage currents through the module's front glass and the encapsulation material. The flow of Na+ ions mainly from the glass into the cell leads to the creations of shunts. For both PID types, module and cell design has a fundamental influence if and how much a module is affected by PID. There are modules on the market which are designed to be PID resistant.</td></tr>
<tr><td>Production ■</td><td colspan="2">Installation ■</td><td>Operation ■</td></tr>
<tr><td rowspan="2">Impact</td><td colspan="4">Yield losses of 20 percent and more within 1 year were observed in the past. The PID-s effect causes a reduction of I-V curve fill factor and output power. Short circuit is affected only in a very progressed state. Due to its catastrophic performance loss PID-s bears a high economic risk. PID-s is to some extent a reversible polarization effect and can therefore 'repaired' or omitted when detected in time. If detected too late the PV system can't be repaired and non-reversible damages has to be taken into account. The PID-p effect causes instead a significant reduction of short circuit current, open circuit voltage and power. PID-p can be fully regenerated by reversing the polarity of the bias potential. Up to now safety problems directly related to the PID are not reported, but hot spots and corrosion caused by the strong cell mismatch may cause later safety issues. The PID sensitivity of PV modules can be tested in the laboratory. Anti-PID insurance can be obtained, although many insurers need to be educated about the phenomenon for correct risk estimation and pricing.</td></tr>
<tr><td>Safety:</td><td></td><td>Performance:</td><td>2 3 4 5</td></tr>
</table>

Component Defect	**Module** **Potential induced degradation (PID) (page2)**		**PVFS 1-10vs.01**
Mitigation	Corrective actions	Preventive actions (recommended)	Preventive actions (optional)
	How to proceed depends very much on the stage on which PID is detected. If detected in an early stage recovery is possible by applying a reverse voltage during night-time. Specific anti PID kits are available on the market promising a recovery of the lost power. As there is not a full guarantee that the recovery will be effective for the specific situation, it should be monitored or measured to see if the problem has been sufficiently solved. In the case of progressed PID without visible module damages, the recovery could need several months or even years suggesting in any case a replacement of all modules with modules tested to be PID resistant.	Modules tested for PID accord. IEC 62804-1 should be less prone to PID (verify that BOM corresponds!)	PID prevention at system level: The installation of an inverter with transformer can be considered as mitigation measure for the PID phenomenon. On the other hand, the trade-off with the inverter efficiency and the cost of the inverter must be taken into account. Anti-PID insurance.

EXAMPLES (page1)		PVFS 1-10vs.01
Examples 1-2		
	Strings with PID, detected with IR thermography. [Köntges14]	Dark IR thermography at Isc for a module affected by PID. [Köntges14]
Severity	2 3 4 5	2 3 4 5
Examples 3-4		
	Strings with PID, detected with EL imaging.	Electroluminescence image made at Isc for a module affected by PID. [Köntges14]
Severity	2 3 4 5	2 3 4 5
Examples 5-6	 	
	PID affected module with power loss of 89%, left: EL at 1.5 x I_{sc}, right: I-V curve of the same module at 1000 and 200 W/m2. [Herrmann21]	PID affected module with power loss of 14%. top: EL at 1.5 x I_{sc}. bottom: EL of the same module at 0.2 x I_{sc}. [Herrmann21]
Severity	5	3