Component	Module	PVFS 1-16vs.01
Defect	**Not conform power rating**	

Appearance

The STC output power of a brand new module is below a specified tolerance limit or the minimum nameplate output power is not clearly specified by the manufacturer.

Detection

IV, (MON)

Origin

Deviations of the measured power of a single module respect to the name plate power depends on the product variability, manufacturing quality, the labelling policy and the measurement uncertainty. The quality of cells (e.g. LID susceptibility) together with the binning method applied in production for the reduction of mismatch losses, has a significant impact on the product variability. The deviations in the measurement in the factory comes from several sources of uncertainty, for example the environment temperature, measured module temperature, calibration of the solar simulation, maintenance of the reference module, measurement equipment, connectors and cables. According to the international standards, the power rating has to take into account any technology related initial degradation effects (for c-Si see FS 1-17). This means that after a first exposure to light the output power of a new module has still to be within the rated power tolerance. The measurement uncertainty of the test laboratory performing the STC performance test has therefore to be taken into account. The modules have to be stabilised according the procedure described in IEC 61215-2:2021. Technology specific test requirements are described in IEC 61215-1-1:2021 to IEC 61215-1-4:2021. Depending on the technology, a maximum allowable measurement uncertainty is defined for the verification of power ratings. For c-Si modules it is specified as 3%. A PV module is considered to be conform to the IEC61215 standard, when following criterion (gate 1) is fulfilled:

$$P_{max}(\mathrm{Lab}) \cdot \left(1 + \frac{\frac{1.65}{2}|m_1|[\%]}{100}\right) \geq P_{max}(\mathrm{NP}) \cdot \left(1 - \frac{|t_1|[\%]}{100}\right)$$

P_{max} (Lab): measured maximum STC power of each module in stabilized condition

P_{max} (NP): minimum rated nameplate power of each module without rated production tolerances

m_1: measurement uncertainty in % of laboratory for P_{max} (expanded combined uncertainty (k = 2)

t_1: manufacturer's rated lower production tolerance in % for P_{max}

The minimum nameplate power rating, $P_{max}(NP)$ and tolerance t_1 has to be derived from the nameplate or data sheet values. If the $P_{max}(NP)$ derived from the datasheet is different from the nameplate value, the module can be considered to be not conform. If the tolerance is not stated on the nameplate or the datasheet, then t_1 = 0. If the tolerance is not reduced to a single value on the nameplate or data sheet (for example, if multiple tolerances or measurement uncertainty components are specified) the smallest number shall be utilized.

Production ■	Installation ☐	Operation ☐

Impact

A non-conform STC power rating is not a real module failure, as it causes no degradation or safety issue, but it has a negative impact on the lifetime energy yield and financial return. An incorrect estimation of the installed STC power has a direct impact on the energy yield predictions and investor expectations.

Safety:		Performance:	1 2 3

Mitigation

Corrective actions	Preventive actions (recommended)	Preventive actions (optional)
Confirm underperformance through an accredited PV test laboratory. Claim for missing power.	Verify power warranties and data sheet conformity, purchase modules from trusted manufacturers.	Independent third party testing of samples at factory gate and/or arrival on site. Signature of a contractual agreements.

EXAMPLES (page1)	PVFS 1-16vs.01

Examples 1

a)

Product Z300W

Maximum power (P_{max})	300 W ±3 %
Maximum power voltage (V_{mp})	37 V
Maximum power current (I_{mp})	8,1 A
Open circuit voltage[a] (V_{oc})	45,9 V
Short circuit current[a] (I_{sc})	8,9 A
Maximum DC system voltage	1 000 V

[a] +5 % / –0 % tolerance

Product Z series
Electrical Data at STC

Peak power watts ±3 % - P_{max} (W)	300	305	310
Maximum power voltage - V_{mp} (V)	37	37,2	37,5
Maximum power current (I_{mp}) (A)	8,1	8,2	8,27
Open circuit voltage[a] - V_{oc} (V)	45,9	45,9	45,9
Short circuit current[a] - I_{sc} (A)	8,9	8,92	8,98
Module efficiency - η_m (%)	14	14,2	14,4

[a] ±5 % / –0 % tolerance on I_{sc} and V_{oc}

P_{max} (NP) = 300 W; t_1 = 3 %
V_{oc} (NP) = 45,9 V; t_2 = 5 %
I_{sc} (NP) = 8,9 A; t_3 = 5 %

b)

Product X300W

Maximum power (P_{max})	296 to 300 W
Maximum power voltage (V_{mp})	37 V
Maximum power current (I_{mp})	8,1 A
Open circuit voltage[a] (V_{oc})	45,9 V
Short circuit current[a] (I_{sc})	8,9 A
Maximum DC system voltage	1 000 V

[a] ±4 % production tolerance

Product X series
Electrical Data at STC

Peak power watts[a] - P_{max} (W)	296 to 300	301 to 305	306 to 310
Maximum power voltage - V_{mp} (V)	37	37,2	37,5
Maximum power current (I_{mp}) (A)	8,1	8,2	8,27
Open circuit voltage[a] - V_{oc} (V)	45,9	45,9	45,9
Short circuit current[a] - I_{sc} (A)	8,9	8,92	8,98
Module efficiency - η_m (%)	14	14,2	14,4

[a] ±4 % production tolerance

P_{max} (NP) = 296 W; t_1 = 0 %
V_{oc} (NP) = 45,9 V; t_2 = 4 %
I_{sc} (NP) = 8,9 A; t_3 = 4 %

If t_1 is not specified, it is taken to be 0.

c)

Product Y300W

Maximum power (P_{max})	300 W ±3 % / -0
Maximum power voltage (V_{mp})	37 V
Maximum power current (I_{mp})	8,1 A
Open circuit voltage [a,b] (V_{oc})	45,9 V
Short circuit current [a,b] (I_{sc})	8,9 A
Maximum DC system voltage	1 000 V

[a] ±2 % measurement uncertainty
[b] ±10 % tolerance on I_{sc} and V_{oc}

Product Y series
Electrical Data at STC

Peak power watts - P_{max} (W)	300	305	310
Power output tolerance (%)	-0 / +3	-0 / +3	-0 / +3
Maximum power voltage - V_{mp} (V)	37	37,2	37,5
Maximum power current (I_{mp}) (A)	8,1	8,2	8,27
Open circuit voltage [a, b] - V_{oc} (V)	45,9	45,9	45,9
Short circuit current [a, b] - I_{sc} (A)	8,9	8,92	8,98
Module efficiency - η_m (%)	14	14,2	14,4

[a] ±2 % measurement uncertainty
[b] ±10 % tolerance on I_{sc} and V_{oc}

P_{max} (NP) = 300 W; t_1 = 0 %
V_{oc} (NP) = 45,9 V; t_2 = 2 %
I_{sc} (NP) = 8,9 A; t_3 = 2 %

t_2 is not reduced to a single value. Thus, the smaller value is chosen. The same situation exists for t_3.

d)

Product T300W

Maximum power (P_{max}) Power selection (±5 W)	300 W
Maximum power voltage (V_{mp})	37 V
Maximum power current (I_{mp})	8,1 A
Open circuit voltage (V_{oc})	45,9 V
Short circuit current (I_{sc})	8,9 A
Maximum DC system voltage	1 000 V

±3 % tolerance on P_{max}, I_{sc}, V_{oc}

Product T series
Electrical Data at STC

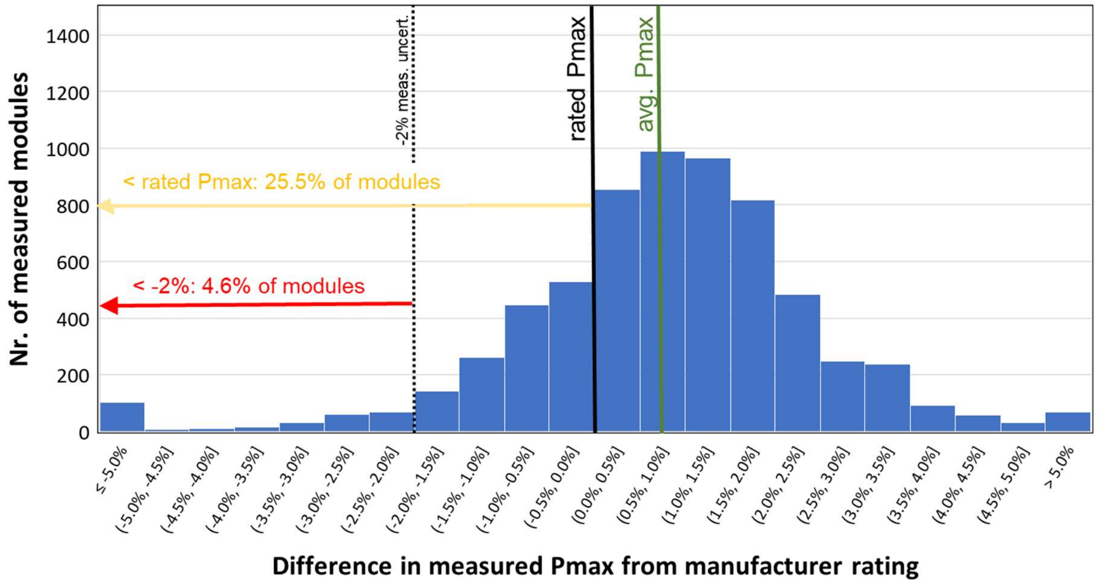
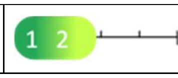
Peak power watts[a] - P_{max} (W)	300	310
Maximum power voltage - V_{mp} (V)	37	37,5
Maximum power current (I_{mp}) (A)	8,1	8,27
Open circuit voltage[a] - V_{oc} (V)	45,9	45,9
Short circuit current[a] - I_{sc} (A)	8,9	8,98
Module efficiency - η_m (%)	14	14,4

[a] ±3 % tolerance on P_{max}, I_{sc}, V_{oc}

Fails to meet requirements of IEC 61215-1 5.2.2. Lower edge of power bin is 295 W on nameplate, but is 300 W on datasheet.

Example of a hypothetical conform (a-c) name plate and datasheet values with on the right the accord. IEC 61215-1:2021 derived rated values and tolerances in comparison to a hypothetical example of a not conform STC rating (d). [IEC 61215-1:2021]

Severity		NA

EXAMPLES (page2)		PVFS 1-16vs.01
Examples 2		
	Statistical analysis done by Eternalsun on around 6500 new modules with 96 different PV module types from 29 different manufacturers. [Herrmann21] Considering the measurement uncertainty of +/-2% a total of 4.6% of the modules are below the gate 1 limit defined by the IEC 61215 standard. [IEC 61215-1:2021] *Note: In case of a measurement uncertainty of +/-5% none of the PV modules would fail, but it would be not conform to the IEC 61215 standard prescribing a maximum measurement uncertainty for c-Si modules of +/-3%.*	
Severity		

Component Defect	**Module** **Light induced degradation in c-Si modules (LID/LeTID)**	**PVFS 1-17vs.01**

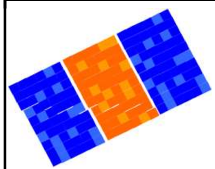
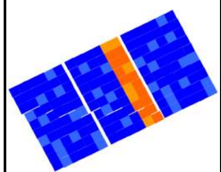
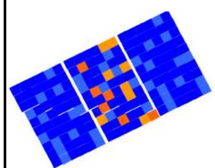
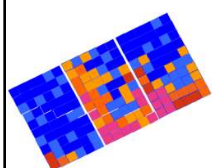
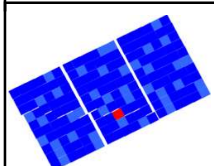
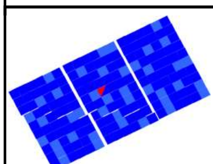
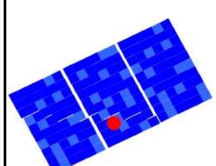
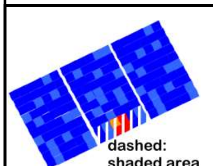
Appearance	Light induced degradation in crystalline silicon modules is recognisable mainly as a drop in STC output power, but also short circuit current and open circuit voltage, within the initial lifetime of a PV system. It isn't correlated with any visual defect or other failure modes. Increasing non-uniformity of electroluminescence images (patchwork pattern) can in some cases highlight an ongoing degradation process.		
Detection	IV, (EL, IRT)		
Origin	Two different light induced degradation effects are known: LID (light induced degradation) and LeTID (light and elevated temperature induced degradation). Both degradation modes occur at cell level, but the physical mechanism staying behind them are different. The first is related to the concentration of boron and oxygen in the cells, whereas the second one is probably correlated to the concentration of hydrogen in the cell, but the mechanisms are still not fully understood. Mainly p-type multi and mono crystalline silicon modules are affected. High-efficiency cell technologies that use n-type wafers, such as n-type PERC, HJT, or n-PERT seem to be much less or not at all concerned by these two degradation effects. LID occurs only within the first days of exposure to the sun and is limited to 1-3%, whereas LeTID is in a more severe and long-term light induced degradation mechanism. LeTID was observed for the first time with the introduction of PERC modules on the market. The degradation can reach up to 10% and sum-up with the LID loss. It occurs only at elevated temperatures above 50 °C. The speed with which the degradation occurs depends on the average module temperature and is therefore strongly site dependent. The time frame in which it occurs is in the order of magnitude of years. Once the full degradation is reached the modules can regenerate, recovering the lost power. This process is however very slow and also climate dependent. The lost power may even not recover over the typically expected 25-year lifetime of a module. There exist approaches of accelerated regeneration of LeTID-sensitive modules in the field, but they are not very user-friendly. Over the last years always more manufacturers adapted their cell production process to stabilise the cells in-line. Different industrial approaches exist for the mitigation of LeTID and depending on the methodology the degradation rates, even if reduced, can differ from one manufacturer to the other and range from 1-4%.		
	Production ■	Installation ☐	Operation ☐
Impact	LID or LETID causes no safety problems, but it has a negative impact on the lifetime energy yield and financial return. An under-estimation of the initial degradation has a direct impact on the energy yield predictions and investor expectations. LID is less critical for the investors, because it is generally less severe and it is taken into account by the manufacturers when labelling the modules and defining the first year warranty, whereas a high LeTID degradation rate and the difficulty to predict the trend over time is much more critical for manufacturers' warranties and system owners. The sensitivity of PV modules to LeTID can be tested in the laboratory. Serious LID above 10% degradation may result in hotspot and can be detected by IR camera, it happened mainly to the cells produced when PERC were just commercialized and no mitigation of LID in the manufacturing process was available.		
	Safety:	Performance: 2 3	
Mitigation	Corrective actions	Preventive actions (recommended)	Preventive actions (optional)
	Confirm underperformance through an accredited PV test laboratory. Claim for missing power.	Verify power warranties. Verify the use of LeTID stable cells by module manufacturer.	Request test reports with % power loss for realistic estimations. Stipulate a contractual agreement on tolerated loss. Test individual modules. Verify BOM (cell type).

<table>
<tr><td>Component
Defect</td><td colspan="2">Module
Insulation failure</td><td>PVFS 1-18vs.01</td></tr>
<tr><td>Appearance</td><td colspan="3">A module with bad insulation between its current carrying parts and the frame (or the outside world) are not directly visible by eye. An unequivocally detection is only possible through a measurement of the insulation resistance of the module under dry (≥40 Mohm/m²) or better humid/wet conditions. It can be sometimes deduced by the presence of visual defects which can potentially lead to insulation problems. Under certain circumstances like after a rain fall or in the early morning when the PV modules are covered by dew, this kind of defect is detected by the inverter (low insulation fault) or the inverter is switching off when the resistance value falls below a certain limit.</td></tr>
<tr><td>Detection</td><td colspan="3">INS, (MON)</td></tr>
<tr><td rowspan="2">Origin</td><td colspan="3">Insulation failures can have different causes. It can occur in the design/production phase of a module, due to solar cells too closely positioned to the frame or to material weaknesses like the use of inadequate encapsulation or backsheet materials or a poor lamination process. In the installation phase it can be caused by mechanical damages of the module, whereas in the operational phase it is generally caused by catastrophic events or due to a delamination process close to the edge of the module or water ingress or condensation in the junction box. Modules with failed or skipped insulation test in production due to an insufficient quality assurance could be also the origin of the problem. Various module failures are at the origin of an insulation failure: backsheet and encapsulant delamination, backsheet damages, burn marks, glass breakage.</td></tr>
<tr><td>Production ■</td><td>Installation ■</td><td>Operation ■</td></tr>
<tr><td rowspan="2">Impact</td><td colspan="3">A low insulation resistance at module level itself does not lead to a performance loss, until an inverter failure occurs. The presence of an electrical leakage current to the frame can become a safety hazard exposing persons to a potential electric shock hazard. Touching non-insulated parts of the string or frame can cause severe injury, without the use of safety gear and safe measuring instruments.</td></tr>
<tr><td colspan="3">Safety: e   Performance: 1 2 3 4 5</td></tr>
<tr><td rowspan="2">Mitigation</td><td>Corrective actions</td><td>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. In case of individual module testing all modules which failed the insulation and/or wet-leakage test should be replaced.</td><td>Check validity of IEC 61215 certification and BOM, commissioning of system with IRT, ground fault detection by inverter or other devices at all time.</td><td>Regular system inspections, Insulation testing of modules with mobile test centre before installation.</td></tr>
</table>

Component Defect	**Module** **Hot-spot (thermal patterns)**	**PVFS 1-19vs.01**

Appearance	A hot-spot is a thermal abnormality such as a local overheating or a thermal pattern which deviates from the normal behaviour of a module. It can be detected only by imaging techniques such as e.g. infrared thermography. Hot spots are not visible by the naked eye until they lead to irreversible hot-spot damages like e.g. local **yellowing, burn marks, glass** or **cell breakage**. The position, size, intensity and pattern of the hot-spot/s depends on the origin and progress of the failure, but also under which conditions the module is operating (shading, load and irradiance level). A temperature gradient of smaller than 10 K is considered as normal and is not a hot spot or thermal abnormality.
Detection	IRT, (VI)
Origin	A hot spot may be caused by shading, soiling, severe cell mismatch, damaged cells (e.g. cell crack and shunted cells), glass breakage, poor electrical connections (e.g. bad or broken solder joints, short circuits, cell interconnect ribbon failures), or low quality solar cell or module production. When such a condition occurs, the affected cell or group of cells is forced into reverse bias and will dissipate power, which can cause overheating. If the power dissipation is high enough or localised enough, the reverse biased cell(s) can overheat resulting in melting of solder, deterioration of the encapsulant and/or backsheet and glass breakage. To reduce the effects of hot spots bypass diodes are connected in parallel to the cells. Well-dimensioned and correctly working bypass diodes helps in reducing hot spot damages from occurring. Production ■ | Installation ■ | Operation ■
Impact	Hot-spots do not always lead to a power loss. Due to normal tolerances in cell sorting and module production, thermal abnormalities of less than 10% of the recorded modules usually do not indicate a special quality issue. Most of the times modules with a single hot cell have an insignificant power loss. Power reduction becomes significant when a permanently activated bypass diode leads to a minimized power output of the affected solar cell string and thus to a reduction of the total module power output. The impact on system level is only visible when more modules are affected. Very high losses can occur when PID is the origin of the warmer cells. Module safety is affected when the overheating causes critical module damages or when it leads to a fire. A temperature gradient in a range of 10 K to 20 K is considered as unproblematic if it is not increasing during the operation of the PV power plant. Temperature gradients above 20 K are expected to cause power losses; in extreme cases, the material compound may even degrade, resulting in a safety issue during maintenance work. Further increase in temperature gradient are expected during the operation phase of the PV power plant if the modules are not replaced. If PV modules of a system are not cleaned and maintained at a suitable frequency, high temperatures of some cells or modules may occur due to bird droppings or power mismatch for a long time which may lead to module damage. At a later stage it might be difficult to evaluate whether the damage was caused by quality problems or by missing cleaning or maintenance procedures. Safety: f | 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 or repaired. If more than 10% modules show thermal abnormalities, the reason for that behaviour should be evaluated and respective corrective actions should be implemented.	Commissioning of system with IRT.	Regular system inspections.

Pattern	Description	Origin	Performance	Remarks	Safety	Power
	One module warmer than others	Module is open circuited - not connected to the system	Module normally fully functional	Check wiring		5
	One row (sub-string) is warmer than other rows in the module	Short circuited (SC) or open sub-string - Bypass diode SC, or - Internal SC	Sub-strings power lost, reduction of V_{oc}	May have burned spot at the module	f	5
	Single cells are warmer, not any pattern (patchwork pattern) is recognized	Whole module is short circuited - All bypass diodes SC or - Wrong Connection	Module power drastically reduced, (almost zero) strong reduction of V_{oc}	Check wiring	f	5 (see PVFS 1-15)
	Single cells are warmer, lower parts and close to frame hotter than upper and middle parts.	Massive shunts caused by potential induced degradation (PID) and/or polarization	Module power and *FF* reduced. Low light performance more affected than at STC	- Change array grounding conditions - recovery by reverse voltage		2 3 4 5 (see PVFS 1-10)
	One cell clearly warmer than the others	- Shadowing effects - Defect cell - Delaminated cell	Power decrease not necessarily permanent, e.g. shadowing leaf or lichen	Visual inspection needed, cleaning (cell mismatch) or shunted cell	f	1 2 3 4 5 (see also PVFS 1-1, 1-3, 3-3)
	Part of a cell is warmer	- Broken cell - Disconnected string interconnect	Drastic power reduction, *FF* reduction		f	2 3 4 5 (see also PVFS 1-1, 1-7, 1-9)
	Pointed heating	- Artifact - Partly shadowed, e.g. bird dropping, lightning protection rod	Power reduction, dependent on form and size of the cracked part	Crack detection after detailed visual inspection of the cell possible	f	2 3 4 5 (see also PVFS 1-1, 1-7, 1-9)
	Sub-string part remarkably hotter than others when equally shaded	Sub-string with missing or open-circuit bypass diode	Massive *I*sc and power reduction when part of this sub-string is shaded	May cause severe fire hazard when hot spot is in this sub-string	f	2 3 4 5 (see also PVFS 1-15, 3-3)

Overview of typical IR image patterns observed in outdoor measuerments. [Köntges14]

<table>
<tr><td>Component
Defect</td><td colspan="4">Module
Soiling</td><td>PVFS 1-20vs.01</td></tr>
<tr><td>Appearance</td><td colspan="5">Soiling is visible as a deposition of dust, dirt or other contaminants on the surface of a PV module. The deposition can be uniform or non-uniform and vary in thickness. Due to the presence of hot-spots caused by non-uniform soiling, it can be also seen through IRT imaging.</td></tr>
<tr><td>Detection</td><td colspan="5">VI, (IRT, MON)</td></tr>
<tr><td rowspan="2">Origin</td><td colspan="5">Soiling of PV modules can have various origins such as dust accumulation, air pollution, bird droppings or growth of moss, lichens or algae. It can be due to natural sources, as sand in desert areas, seasonal pollen or volcanic emissions, or due to human activities, as near mining, industry, high ways, railways, urban or agricultural surroundings. The soiling level and its persistence over time depends on the exposure time, the chemical composition and particle size as well as the local climate conditions. Whereas rainfalls and wind can lead to a natural cleaning of modules, humidity can have a contrary effect by increasing adhesion and cementation of dust on the module. The module design (e.g glass coating, frame, distance of cells from the edge), the orientation (e.g tilt angle, azimuth, landscape/portrait) and mounting conditions (e.g clamps, height above ground, stringing) of the modules plays an important role. Typically soiling increases as tilt angles decreases. The direction of the wind or obstacles can influence the soiling process, leading to non-uniform patterns on system and module level.</td></tr>
<tr><td colspan="2">Production ☐</td><td colspan="2">Installation ■</td><td>Operation ■</td></tr>
<tr><td rowspan="2">Impact</td><td colspan="5">The deposited soiling layer causes optical losses, reducing the amount of light that reaches the solar cells, with a consequential performance drop. Soiling is not a real module failure, as it is reversible when the module is cleaned, but it has a negative impact on the lifetime energy yield and financial return. Soiling is a site-specific issue. In arid regions with seasonal dry periods and dust, extreme soiling losses of up to 25%/a are reported, if modules are not cleaned. In temperate regions with year-round rain, the annual soiling losses typically ranges between 0% to 4%. In case of specific soiling sources (e.g. railway, farming, etc.) and/or constraints of the natural cleaning effect due to unfavourable mounting conditions (e.g low tilt angle) much higher losses can be observed. Non-uniform soiling leads to current mismatch losses which further increases the power loss and to hot-spots which in extreme cases can permanently damage a PV module. In modules affected by potential induced degradation (PID), soiling can further accelerate the ongoing degradation effect. Soiling can be mitigated by cleaning the modules or preventing excessive soiling. The cleaning approach has to be appropriate to the type of soiling and site specific conditions (e.g. accessibility and water availability). The cleaning schedule should take into account that natural agents, such as rain-falls, wind or dew can have a natural cleaning effect at no cost. Anti-soiling coatings (ASC) can help in reducing soiling and stretch the cleaning frequency, but only if the coating is adequate for the type of soiling present on the system and if adequate cleaning processes are followed, which do not damage the coating. Moreover, it has to be considered that some ASC can also increase transmission losses by themselves.</td></tr>
<tr><td>Safety:</td><td></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>Preventive actions (optional)</td></tr>
<tr><td colspan="2">Cleaning by qualified persons is recommended when the revenue lost because of the missed energy production is higher than the cleaning cost. A best time to clean should be defined.</td><td colspan="2">Preliminary site inspections for the assessment of the soiling risk. Cost estimation for the implementation of mitigation measures. Regular visual inspections to control the soiling level.</td><td>Estimation or measurement of soiling losses prior to installation. Installation of soiling sensors to determine the most profitable time to clean.</td></tr>
</table>

EXAMPLES (page1)			**PVFS 1-20vs.01**
Examples 1-3			
	Uniform light soiling, which in ideal conditions is self-cleaning when raining.	Uniform heavy soiling caused by rail way station. [SUPSI]	Non-uniform soiling caused by low inclination and close mounting to roof. [SUPSI]
Severity	2	3 4	2 3
Examples 4-6			
	Moss growing on the edge of a module combined with edge soiling. [Köntges17]	Soiling pattern on a system in the Atacama desert. [ISE]	Soiling pattern demonstrating dominant wind direction on a test site in Atacama desert. [ISE]
Severity	e 2 3	3 4	3 4
Examples 7			
	Heavy biofilm soiling. [Köntges16]		
Severity	4 5		