Minimising risk from plant performance defects

Plant defects | To ensure profitability in PV power plant investments it is crucial to minimise operation risks in the early stages of project development and during planning, installation and commissioning. Potential performance losses and the economic risks due to failures in plant design, employed components and construction must be considered, as Willi Vaaßen of TÜV Rheinland explains

Credit: TÜV Rheinland.

Declining costs, a growing energy demand in many countries and government incentives have diversified the worldwide solar investment landscape. Every few weeks a new potential solar hotspot shows up on the global solar map, attracting investors and project developers of PV power plants. Particularly in countries with little experience in large-scale installations, it can be quite risky to count on a quick return on investment if quality is not ensured, however. Indeed, the golden days of double-digit returns on equity are gone for most projects in the solar industry. Small losses in performance can already lead to drastic cuts in profit.

Given a calculated return of (e.g.) 5%, a slight loss in performance of (e.g.) 1% will already lead to a 20% loss in the planned return. In terms of absolute numbers, a power loss of 1% in a 100 MW PV power plant can result in a loss of earnings of more than 3 million euros over 20 years.

Causes of faults and performance losses

To avoid faults, their potential causes must be analysed. Here it is important to consider the project phases during which the faults arise, the affected components, the effects these faults can have and how they can be prevented.

The minimisation of operational risk of a PV power plant begins during the planning phases.

A recent analysis of PV power plants globally inspected during commissioning and after a few years of operation by TÜV Rheinland during 2014 and the first quarter of 2015 (see figure 1) revealed 40% of the detected defects to be installation faults. Thirty-two percent were planning and documentation errors, 17% product defects or performance deviations and 8% environmental effects, such as sand or dust pollution as well as shading.

Given these causes of faults, we see that quality assurance measures for fault avoidance must be implemented in the early beginning stages of project development and system planning. The concrete

> "Small performance losses can already lead to drastic cuts in profit"

reality of new subcontractors often being employed who in turn outsource partial tasks can lead to an unmanageable flood of faults even for established EPCs.

The rectification of these defects, which often involve safety issues and can therefore threaten the life and limb of the operations and maintenance (O&M) personnel or which may be revealed only in the medium term through fast wear, early part failure or higher maintenance costs, can prove very labour-consuming and costly later on. Severe weather conditions (e.g. hail, lightning, storms, etc.) can also cause damage to unprofessionally planned and installed systems. If redress can then no longer be taken against participating companies because they have since become insolvent or because the warranty has expired, the costs will generally hit the investor or owner of the facility.

Loss of revenue factors

Risk factors for PV power plant investments can be roughly categorised according to technical, financial and legal and tax-related aspects. Of course, all risk areas are affected by the technical risks, since the object of investment is a technical facility that can be operated economically only if it delivers the predicted yield in the long term. To this end it must be optimally planned and implemented. The selected components must of course also meet this requirement.

Although the photovoltaic industry is no longer in its fledgling stages, the quality available on the market is far from meeting this requirement, for a variety of reasons. In part, module and other component production has grown too fast and has suffered substantial financial losses in past years. The boundary conditions do not obtain for complying with the utmost quality demands, should this even be attempted. This fact is also evident from the failure of a few quality providers in this market situation. Dubious vendors and practices make quality assessment difficult.

On paper, module and component quality has changed for the better over the last years because the results of type tests have improved. However, as previously mentioned, many manufacturers are suffer-

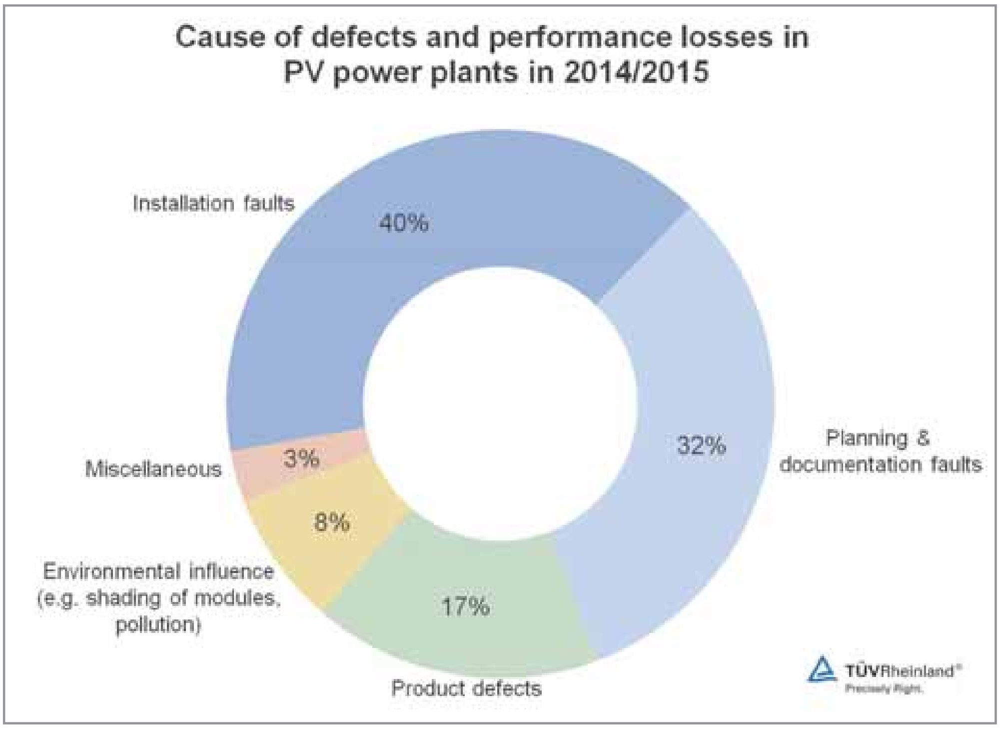

Figure 1: Causes of faults and performance losses in PV power plants during 2014/Q1 2015

Figure 2: Categorisation of risk factors for PV power plant investments

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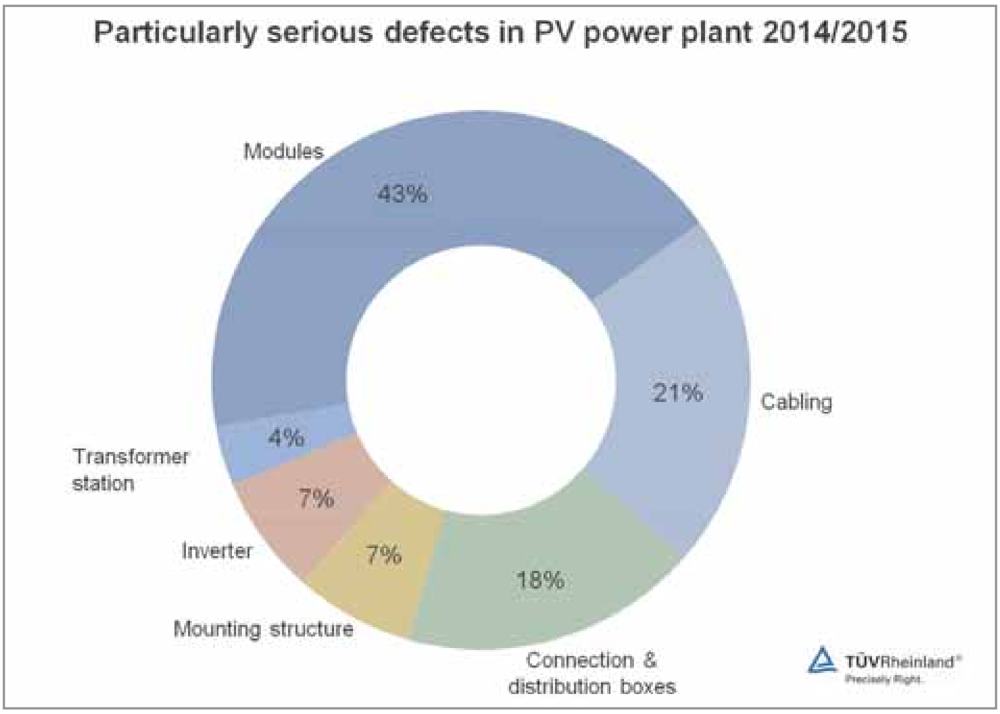

Figure 3: Particularly serious defects in PV power plants 2014 - Q1/2015

ing from heavy cost pressure due to worldwide competition and organising their market entry with minimal effort. Continual quality assurance of processes, materials or qualified staff is often lacking. IEC certification is consequently only a minimum requirement and is unsuitable as proof of continuous quality. Adequate factory inspections or the sufficient quality of the materials used is not always secured.

The quality of the installed PV modules in the field has therefore even decreased over the last few years, as TÜV Rheinland inspection reports indicate. The share of modules with particularly serious or serious defects rose from 25% in the years 2012-2013 to 34% in the years 2014-2015.

Quality – and primarily technical quality is at issue – must therefore be rethought and put into practice by the users (investors, banks, operators, insurance companies). It is certainly helpful to employ institutions, like TÜV Rheinland, which know the risks through many years of international field experience and laboratory testing and are therefore able to prevent faults.

The following fault analyses and technical risks should provide the requisite information to this end. For its studies TÜV Rheinland employs the FMEA (failure and mode effect analysis), which affords a representation of the effects of faults on performance and therefore on the economic success of the plant.

Particularly serious defects, serious defects and less serious defects

The fault analysis distinguishes between three categories of defects: particularly serious defects, serious defects and less serious defects. Particularly serious defects require immediate action to prevent the breakdown of the overall PV plant. In case of serious defects, plant operation is possible but the defects must be rectified. In the case of less serious defects, there is no compelling need for action but observation is recommended. In total, over 30% of the inspected PV power plants showed particularly serious or serious defects.

The especially serious defects of modules identified, such as glass breakage, burnt junction boxes or defective back sheets, are caused by either product defects or by inappropriate installation. Delamination and potential-induced degradation comes from product deficiencies. Other frequently occurring cases are missing covers of connection and junction boxes (no protection against electric shock), damaged cables, burnt-down connectors, transformer stations with blocked panic locks, inverters out of operation or mechanically damaged mounting structures. Instant countermeasures had to been taken when modules with glass breakage or burnt junction boxes were found.

With a share of 43%, modules were by far the items most affected by particularly serious defects in PV power plants in the years 2014 to Q1 2015 (see figure 3). As shown in Figure 1, the causes were product failures as well as a high rate of installation errors. These factors are followed by cabling (21%) faults and defects in connection and distribution boxes (18%).

Figure 4 shows the distribution of serious and less serious defects. Here the preponderance of fault occurrences shifts. Besides the PV modules, faults in cables and lines, connectors, connection & distribution boxes and in mounting systems occur to an increasing extent. Installation and mounting faults are often concerned here. Unfortunately, however, the number of product faults in so-called Balance of System (BOS) components is also increasing.

The selection and purchase of these components is the responsibility of the EPC, which has the overall responsibility for planning, selecting components and constructing the plant. The EPC must be urgently advised to make a careful selection of components. The choice of certified products is certainly an important criterion here. Unfortunately, the quality of the actual plants often differs from the tested quality in the

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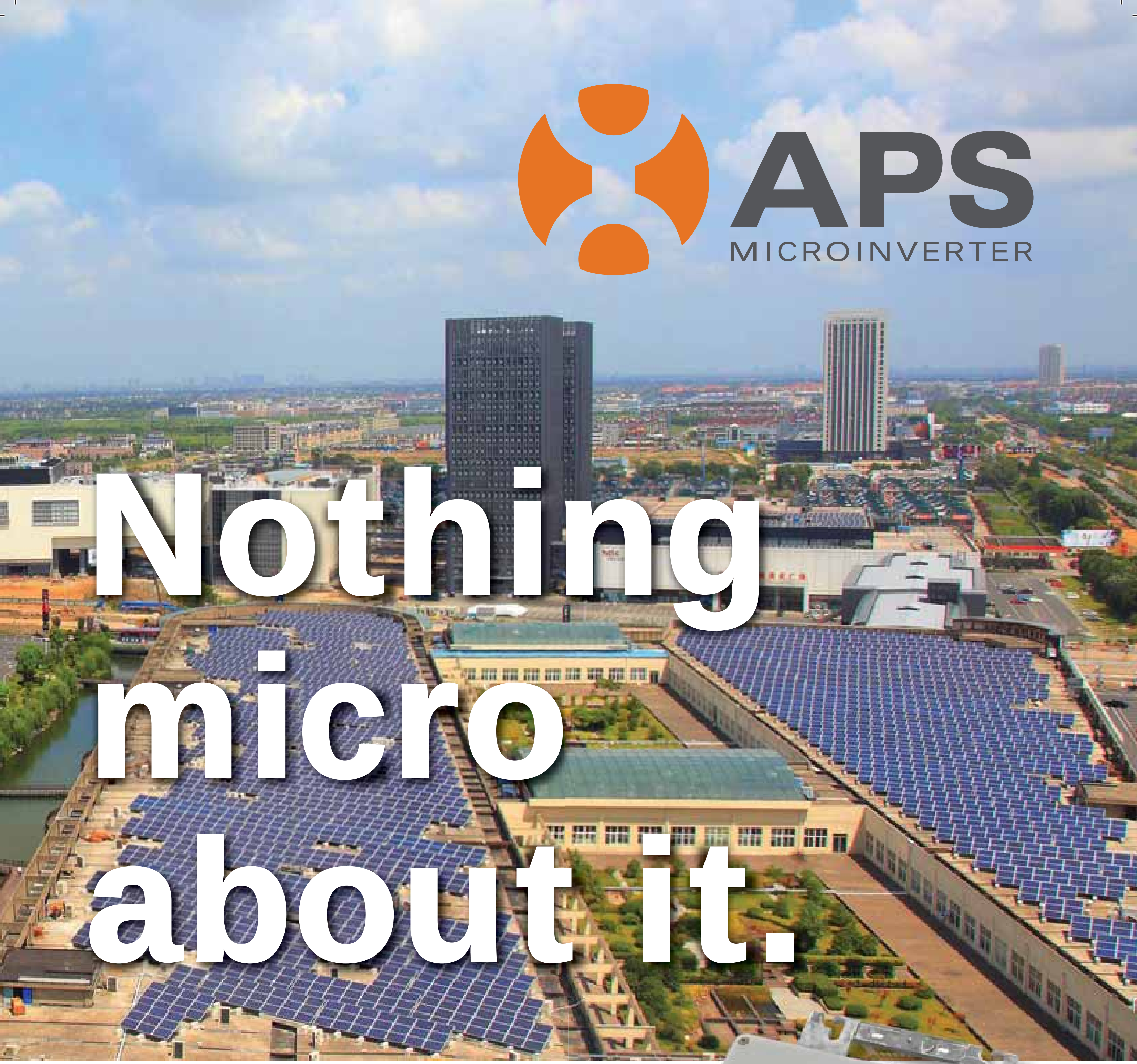

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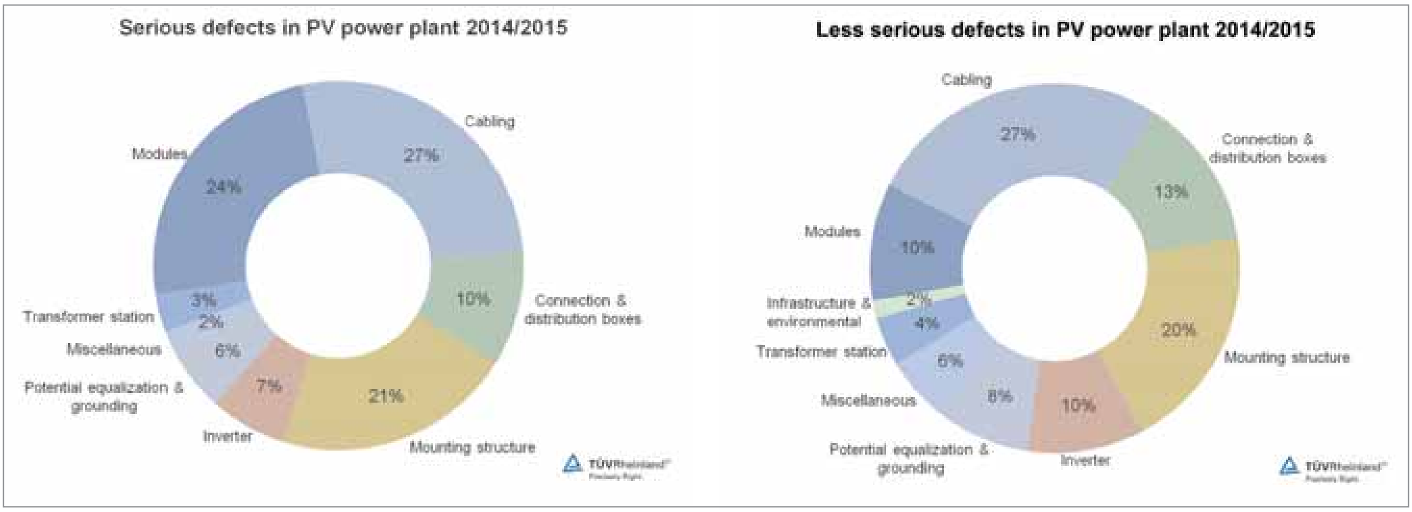
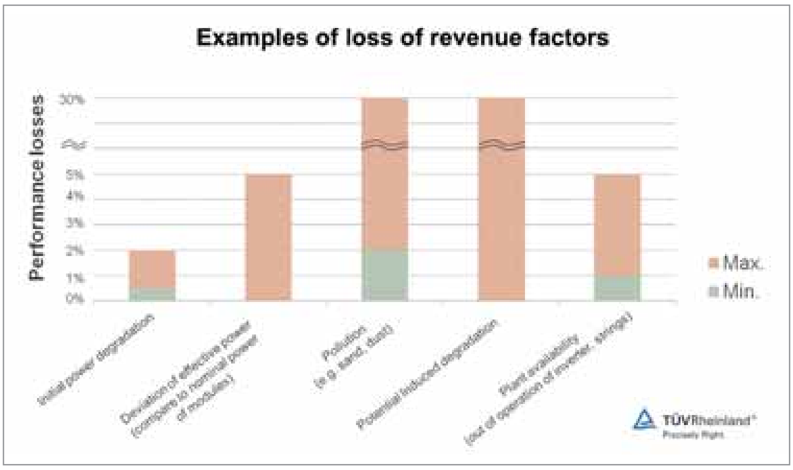
Components	Category	Defects (examples)	Example
Modules	PSD	• PID • Undervalued power, glass breakage, delamination • Burnt junction box	Delamination 
	SD	• Defective backsheet • Browning, serious microcracks	
	LSD	• Module frame damaged • Snail tracks	
Inverters	PSD	• Out of operation	
	SD	• Insulation faults • Not suitable for local environmental conditions	
	LSD	• Inverter door without filter	
Connection & distribution boxes	PSD	• Missing cover	Burnt cable terminals 
	SD	• Burnt connection, surge protector out of operation • Water in distribution box • Wrong fuse rating	
	LSD	• Missing labels • Dirt inside	
Mounting structures	PSD	• Unstable, damaged • Weak anchorage	Poor foundation 
	SD	• Missing edge protection • Screw not fixed in place • Module clamp not tightened	
	LSD	• Corrosion	
Cabling	PSD	• Connector charred/burned • Damaged cable	Corroded socket/plug 
	SD	• Different connector type • Not UV resistant • Improper insulation • Wrong dimensioning	
	LSD	• Not fixed (loose) routing	
Potential equalisation & earthing	SD	• Missing or improperly secured potential equalisation	
	LSD	• No corrosion protection	
Weather station	LSD	• No maintenance or calibration logs • Wrong location or orientation of sensors	
Infrastructure, environmental influence	SD	• Shading • Land slide due to bad drainage system	Shading by vegetation 
	LSD	• Fence damaged • Refuse at the plant	
Communication & monitoring	SD	• No communication link to inverter	
	LSD	• Incorrect data transmission	
Transformer station	PSD	• Panic lock blocked	
	SD	• Insecure access • Improper cooling system	
	LSD	• Refuse in station	

Table 1: Examples of particularly serious defects (PSD), serious defects (SD) and less serious defects (LSD).



▲ **Figure 4: Serious defects and less serious defects in PV power plants, 2014 to Q1 2015**



◀ **Figure 5: Risks of performance losses, loss of revenue**

certification. Longitudinal water damage to cables or contact problems in the use of connectors from various manufacturers (to mention only two issues) can result. In very large plants more than 100 kilometres of cable or million connectors are installed, for example. This shows the risk that exists with systematic defects in the components. Additional spot checking in the laboratory would afford assurances that the applied product corresponds to the certified product.

Examples of serious defects, where operation was still possible but repair was necessary, were modules with defective backsheets, inverters with insulation faults or missing communication links, water in distribution boxes, missing edge protections on mounting structures or improper insulation of cabling. Moreover, repair was necessary for improperly secured potential equalisation, module shading or insecure access to the transformer station.

Effects of typical defects on the energy yield

Figure 5 illustrates some typical defects that can lead in part to considerable performance losses and consequently to financial losses of (e.g.) up to 30%. These defects can be prevented in part with low expenditures in quality assurance.

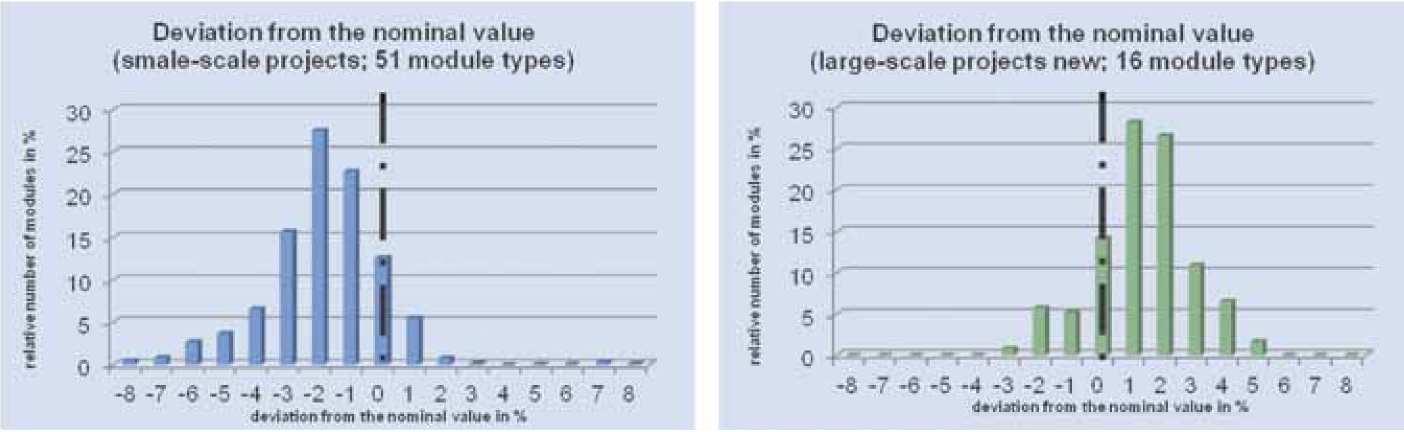
Measurement experiences at the laboratories of TÜV Rheinland show that light-induced degradation (initial degradation) occurring during the first few days of outdoor exposure in PV modules can amount up to 2%; in exceptional cases even higher levels are possible. These losses should be taken into account by the manufacturer when specifying performance, which actually occurs only seldom, however. If the manufacturer supplies flash lists, the flash data likely will not include any initial degradation, since the latter will occur only following installation under constant light conditions. It may therefore happen that following the initial degradation, after a few days of operation the modules will deliver up to 2% less power than indicated in the flash lists. Whether the selected module type undergoes initial degradation can be verified by a corresponding measurement on individual modules of a type series. It must then be clarified with the manufacturer how this can be taken into account in determining the installed performance to be charged.

Another risk factor is that the actual performance of the delivered PV modules will not correspond to the specified performance and the performance to be charged – often documented by the manufacturer's flash data. Figure 5 shows a possible deviation of up to 5%. The deviations lie within the low percentage range, but in exceptional cases are higher. Actual measurement values from the laboratory appear in Figures 6a and b. The various causes may lie in the labelling or in the flash measurement of the PV modules at the manufacturer's plant. A simple control measure and remedy can lie in generally recognised and representative random measurements, which should be contractually agreed upon prior to delivery. If a representative sample seems too large for economic reasons, the parties may agree on a smaller sample size.

A major risk factor is pollution, which can cause revenue losses of up to 30% in very dusty or sandy surroundings. During project development, energy yield predictions must therefore always consider such losses and a reasonable cleaning concept must be implemented and/or more dirt-resistant modules chosen.

Potential-induced degradation (PID) can be the number one performance killer. Here it is important to determine in an early phase of the project whether modules exhibit this effect. If so, it must then also be determined whether appropriate countermeasures are to be implemented during installation or whether PID-free modules are required, and these requirements must be documented in the laboratory through the corresponding measurements for the material combinations used in the project for the given module types.

During plant operation the goal should



▲ **Figure 6: Project-related and precise module performance measurement, a: retroactive, b: contractually foreseen prior to installation**

be pursued of attaining 99% plant availability. This level is possible only with a high-quality plant and only if an O&M concept with short detection and reaction times in case of faults is available. Maintenance agreements with the appropriate content must be concluded.

The challenge in general is to minimise these technical risks and ensure a return on investment through an integrated approach and independent technical consulting throughout the entire project implementation and operation period. It is advantageous to tackle problems in the early stage of project development, however, including module and product testing.

Importance of project-related module testing

The results underscore the importance of the precise laboratory testing of modules, careful product sourcing and diligent planning as essential to the risk minimisation for PV power plant investments.

Example 1: Project-related and precise performance measurements are essential

Precise performance measurement of modules is essential for protecting the return on investment, as measurements by TÜV Rheinland demonstrate (see Figure 6). Over 65% of 51 tested module types (in small-scale projects) showed a deviation from the nominal value of -3% to -1%. The measurements were carried out in part after installation following doubts about the performance of the modules. The modules were new or in mint condition with an operating period of less than one year. In most cases their actual power was lower than that listed by the manufacturer at the outset.

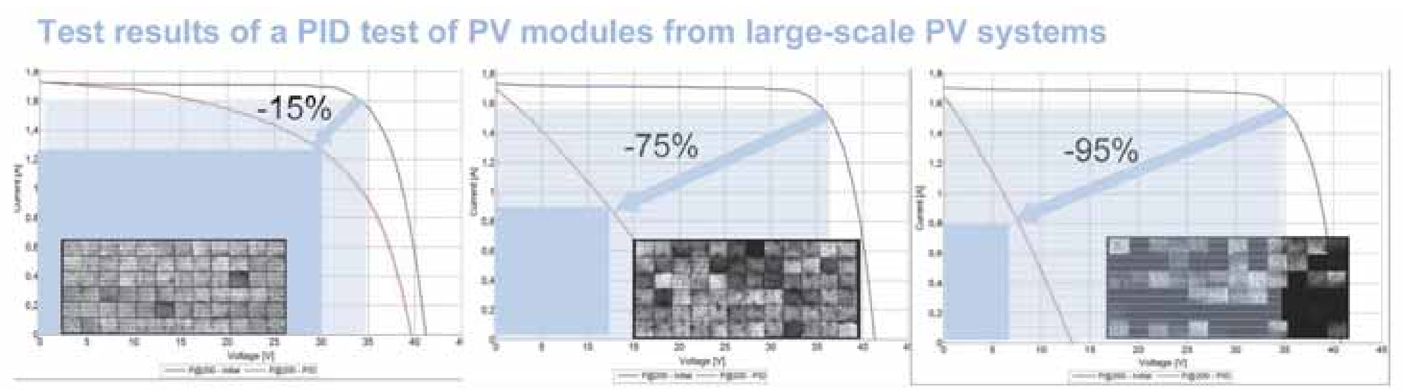
> "Performance killer number one is PID"

Compared are the performance results of 16 module types with contractually agreed precise measurements prior to installation (in large-scale projects). Over 60% of such module types showed a deviation from their nominal value of +1% to +3%, a difference of up to +6% in performance compared with the retroactive measurements. Apparently manufacturers had begun concluding contractual agreements on measurements during the PV power plant planning phases and delivered better modules. Even if we deduct the possible initial degradation occurring within a few days during outdoor exposure at a level of up to 2%, most of the contractually agreed measurements (figure 6b) will attain or exceed the nominal power.

Another important aspect is that a high level of measurement accuracy is required for a high level of acceptance at the manufacturer's site or for use of the measurement results in judicial proceedings. Measurements in the field are rarely helpful in the verification of performance, since the measurement uncertainty even of many mobile systems is greater than 5% and because critical measurement results are generally questioned by manufacturers.

Example 2: Special risk of potential-induced degradation (PID)

Performance killer number one is the potential-induced degradation (PID) of modules, however. It occurs in cases of high voltage, sensitive module material combinations and moist environments due to (e.g.) condensation and high humidity, and leads to gradual losses in performance. PID is often underestimated and its results are



▲ **Figure 7: Special risk: potential-induced degradation (PID)**

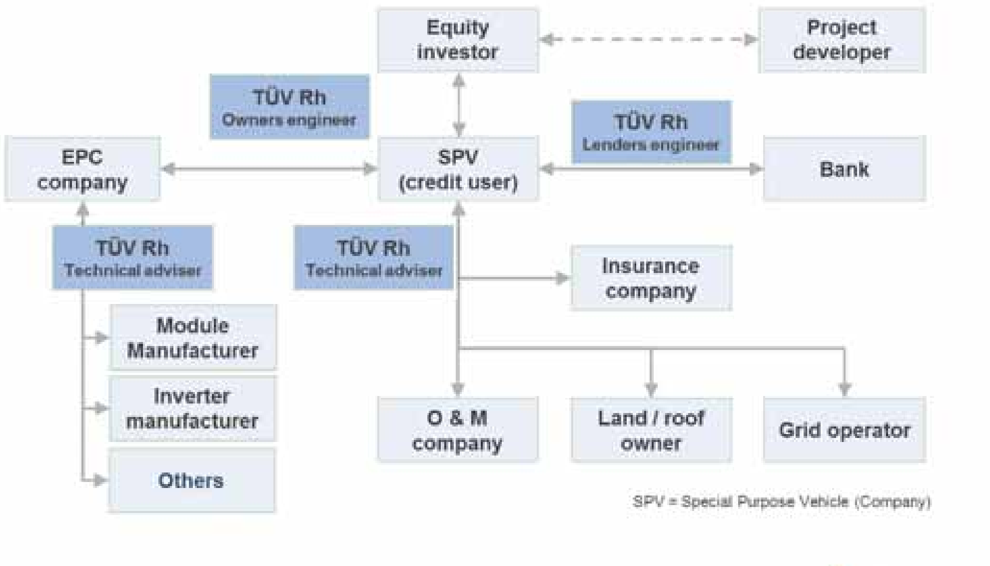


Figure 8: PV power plant project organisation

disastrous. Power plant performance losses of 10% to 30% or more are not infrequent. Fortunately, the effect is mostly reversible; the implementation of suitable measures in the plant, which require in part higher investments can regenerate the modules.

For preventing such losses, the knowledge of the PID sensitivity of modules is essential. All possible material combinations for a given module type (different cells, glass, EVA, backsheet) must be considered before declaring it PID-resistant. The supposedly PID-free PV modules offered with various certificates therefore cannot be fully trusted. In many cases this certification will apply only to a single material combination and not to all different combinations falling under a type designation.

Figure 7 shows the deformation of the characteristic curves of the solar modules depending on the severity of the damage and the related reductions in performance (-15%, -75%, -95%), represented by the reductions in area from the given light performance rectangle of the undamaged characteristic curve to the dark rectangle of the damaged characteristic curve. The effect is also discernible at the electroluminescence images. The greater the number of dark or black cells, the larger is the inactive or less active sector of the modules.

All the more important is the testing and manufacturer-independent consulting that TÜV Rheinland can provide. For finding worthwhile solutions, the bill of materials (BOM) for the modules to be produced for a given power plant must be defined and the correspondingly designed module tested in the laboratory to ensure PID-resistance and sustained revenue. Useful design optimisations of the modules include (e.g.) the use of denser silicon nitride layers for cells, high resistant EVA for module encapsulation and PID-inhibiting coatings for the glass or increasing the current leakage paths by use of frameless modules. The goal is to inhibit ion current to the PN junction.

Importance of independent advice

The risk distribution in large projects depends on the project structure. Very often a structure will be selected like the one in Figure 8. The investors establish an SPV (special purpose vehicle) for implementing the project. For the investors in this construct it is important that the SPV not enter into incalculable risks and that a corresponding position be assumed towards the EPC and other parties.

For controlling the risks, ensuring quality and preventing profit loss, the integration of neutral technical advice in PV power plant project organisation is crucial. One possibility is for the third party to act as an owner's engineer in this case. Another way is to act as a lender's engineer for the bank, with a strong focus on neutral technical consulting within the scope of the bankability inquiry.

At all interfaces in the project, neutral consulting provided by a technical advisor is possible and useful. This neutrality is based on the fact that no product recommendations are made, but rather that the protective aims, requirements and criteria to be fulfilled are defined and laid down on the basis of many years of field experience and product testing. The services include consulting on all technical aspects of site evaluation, energy yield prediction, planning, design, contracts, qualification of components and approvals.

Risk mitigation through quality assurance

There are substantial risks for PV power plant investments. The experience already existing in different markets with the many implemented projects over the last few years has unfortunately not led to a reduction in risks and in defects. Besides the many installation errors, grave product weaknesses repeatedly occur in (e.g.) the PV modules that significantly can diminish plant performance from the outset or lead to an increasing loss in the overall return on investment during operation.

Only comprehensive quality assurance during all project phases provided by qualified and neutral technical adviser can prevent serious defects. If this technical consultant has many years of experience with PV plant inspections, is active in standardisation and in applied research and knows the potential product weaknesses from the many product tests, risks can be significantly reduced. ■

Author

Willi Vaaßen has several decades of experience in the field of PV plant qualification and monitoring, laboratory module and component testing, performance measurement and failure analysis. He is an active participant in several applied research projects. Holder of a university degree in engineering, Mr Vaaßen serves as director of the Global Competence Centre for PV Power Plants (globally, over 12 GWp are inspected) and is head of the Business Field Solar Energy and authorised officer at TÜV Rheinland, Cologne (Germany).

References

[1] "Securitisation of PV Power Plant Performance – Experience with Field Inspections, Failure Analysis, Minimisation of Risks" – Willi Vaaßen, Uwe Hupach, Herbert Becker, Lawrence van Rensburg [TÜV Rheinland]; 2014 Africa Photovoltaic Solar Energy Conference and Exhibition

[2] "From Module to Grid – Recognizing and avoiding weak points in PV Systems" – Uwe Hupach [TÜV Rheinland]; 1st Inverter and PV System Technology Forum 2011

[3] "Review of PV Module Failures" – Ulrike Jahn [TÜV Rheinland], et al.; IEA-PVPS Task 13 report; 2014

[4] "Potential Induced Degradation (PID) of crystalline PV modules" – Gerhard Mathiak [TÜV Rheinland]; 27. Symposium Photovoltaische Solarenergie Bad Staffelstein; 03/2012

[5] „Worauf Sie sich verlassen können – Prüfsiegel und Zertifikate: Qualitätsaspekte bei Solaranlagen" – Jörg Althaus [TÜV Rheinland]; BWagrar; 03/2014

[6] „Photovoltaik Module Technology" – Jörg Althaus [TÜV Rheinland]; 11. Workshop „Photovoltaik Module Technology"; 11/2014

[7] "The land of rising risk?" – Fred Martin, Nick Morley [TÜV Rheinland]; PVTech 02/2015