Project assessment for bankability: Quality assurance from the PV module through system planning to sustainable operational management

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ABSTRACT

Economic success in operating PV systems depends essentially on the likelihood of their long-term operation and their delivery of the expected energy yield. These requirements, for which a lifetime of 20–25 years is often assumed, are demanding and cannot be met without preparation. Preconditions are the acceptable quality and long-term stability of the products employed (particularly the PV modules, but also all other components and materials) and the absence of damage to these items during transport and handling. Moreover, PV systems must be professionally planned and properly implemented. This includes considering energy yield assessments not only in the initial estimation of the energy yield, but also in the subsequent planning for concrete implementation. In addition, professional operational management and appropriate maintenance measures will ensure operation with maximum availability. Yield insurance policies can safeguard profitability and render the risks calculable; various models exist for this purpose and these must be carefully tested. It is important that the insurances services also cover the possible insolvency of the responsible system and component suppliers.

Module quality as an important prerequisite of stable system operation

In determining module quality, the testing and certification of crystalline photovoltaic modules as per IEC 61215 (design qualification) and IEC 61730 (safety qualification) commonly and indeed rightly serve as minimum requirements. For thin-film modules, adequate standards are applied. Testing according to these standards concerns, among other things, electrical safety, mechanical suitability and the ageing behaviour of the products as exhibited in climate chambers. The point of these tests is to detect early failure and design faults in the module production or component selection. This procedure is an important quality check, an indication of which is the fact that about every fourth module type fails to pass the lab testing for certification in accordance with the aforementioned standards.

Many individual tests are combined with one another in the testing procedure. Especially high failure rates (about half of all faults) occur in the climate chamber tests, but in the damp-heat and thermal-cycling tests in particular (Fig. 1). The damp-heat test accelerates material corrosion and often results in noticeable discolouration or voids in the encapsulation material, indicating the unsuitability of polymeric materials and adhesives. Delamination at the interfaces

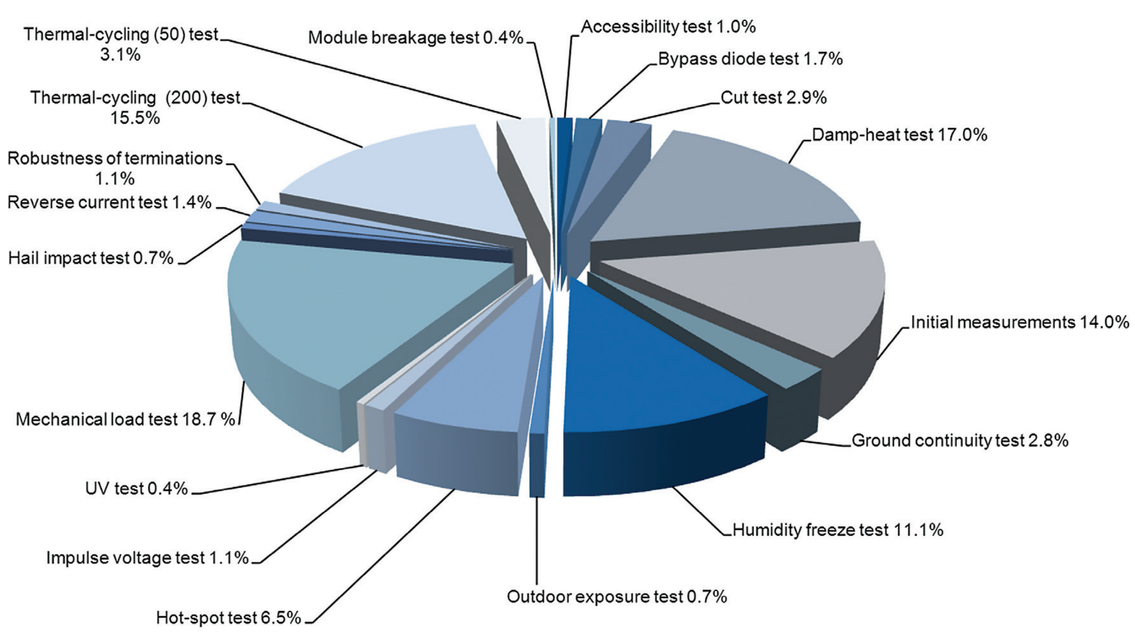

Figure 1. IEC 61215: failure distribution in the certification of crystalline PV modules.

between materials is also a major cause of failure. (Test conditions: 85°C/85% RH, 1000 hours.)

The thermal-cycling test is basically a mechanical fatigue test, in which differential thermal expansion may cause cells or interconnects to crack. This test can also address any thermal mismatch between components. (Test conditions: 200 temperature cycles between −40°C and +85°C, current injection for temperatures >25°C.)

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These type approval tests, however, do not guarantee that all manufactured PV modules will have the same quality as the tested modules. This guarantee can be obtained only from continued quality assurance at a high level. In particular, no material modifications may be made without further testing while keeping production processes the same.

The threat to fulfilling the demand for quality posed by the significant cost pressure and the search for inexpensive materials and procedures is not just a theoretical one. Unfortunately, negative operational experience and deficient quality are testifying to the reality of this threat to an ever-increasing degree. TÜV Rheinland seeks to counteract this trend by now performing production inspections, which were previously annual, more frequently, and also unannounced.

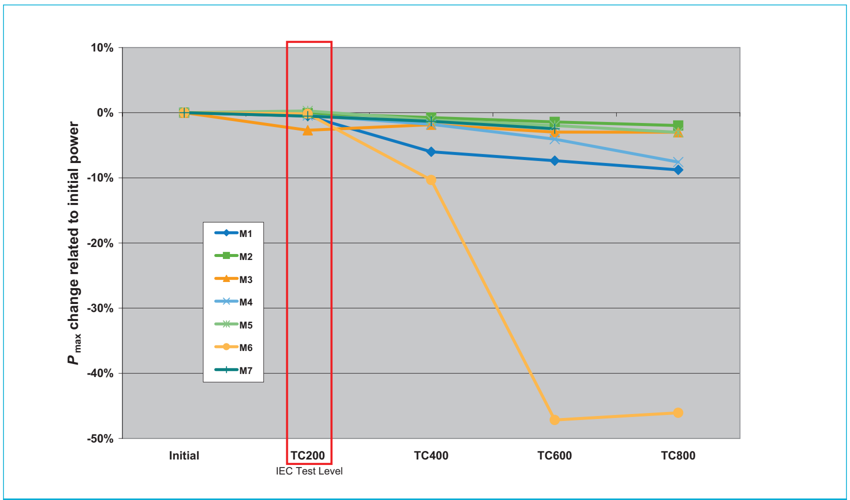

Figure 2. Maximum power degradation during an extended thermal-cycling test.

Can a PV module lifetime of (for example) 25 years be derived from the IEC tests if passed?

The question whether a module that has been certified in accordance with IEC 61215/61730 has a service life of 25 or more years cannot be affirmatively answered, according to the current state of research; nor does the lifetime issue form the background of these standards. Failures occurring up to the end of service life are not covered by these test procedures. Furthermore, the time of the end of life cannot be determined or predicted. Because of the complex stress placed on PV modules during long-term outdoor exposure, no informative and practical test seems to be foreseeable at present. If the acceleration factors are too high, the results will become too far removed from actual exposure conditions and actual ageing. Another

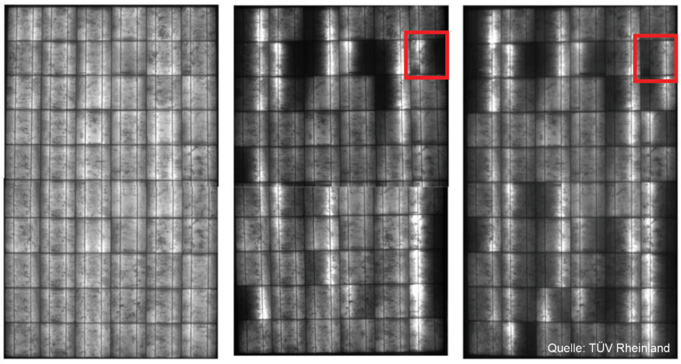

Figure 3. EL images of a module during an IEC temperature-cycling test: 200 cycles (left), 400 cycles (centre) and 600 cycles (right). For the cell outlined in red, the crack of the cell connector after TC400 could not be verified after TC600.

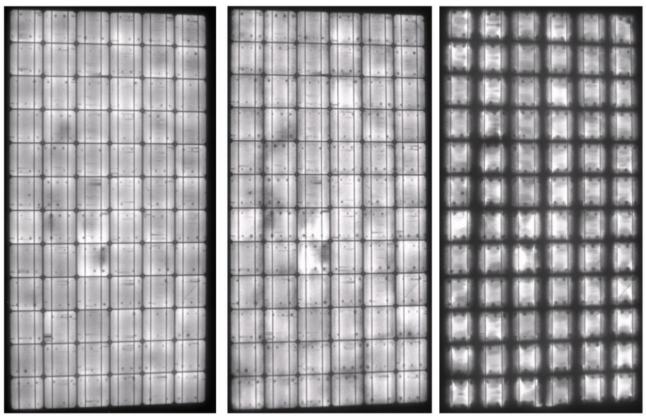

Figure 4. EL images of a c-Si module in extended damp-heat testing: 1000 hours (left), 2000 hours (centre) and 3000 hours (right).

possibility is to develop ageing models for the materials employed in the module group, and to verify and validate these models through concrete operational experience over several years. However, it must be assumed that other material combinations and manufacturing procedures will continue to be used in the construction of modules until these results become available. The present situation is such that even future test procedures will never allow an exact determination of the service life in acceptably short periods of time.

Accelerated laboratory testing (thermal cycling and damp heat)

For the further analysis of degradation mechanisms, the two aforementioned climate chamber test methods (thermal cycling and damp heat) are currently being used in extended test cycles and discussed. The idea being pursued is to estimate the risks to lifetimes via comparisons of the results of the extended test sequences when different module types are used.

Accelerated thermal-cycling testing

In order to study the degradation processes due to thermal cycling, extended temperature-cycling tests were conducted on seven c-Si PV modules, with intermittent diagnostic measurements at 200, 400, 600 and 800 cycles. Fig. 2 shows the measured power degradation curves for the seven test samples: the modules clearly fulfil IEC 61215 test requirements (TC200). Extended qualification testing revealed that more than 400 cycles were needed to observe failures in the interconnection circuit. At the end of the test, three modules still satisfied the IEC 61215 requirements after TC800.

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Tests have shown that breakage of cell connectors is the prevailing degradation mechanism in thermal-cycling tests of c-Si modules. Electroluminescence (EL) analysis proved to be the appropriate method for identifying cracks in internal wiring, but may not find all failures in the cell interconnection circuit. As an example, Fig. 3 shows EL images of the module with the highest power degradation, taken at 200, 400 and 600 temperature cycles. Variations in brightness across the cell area indicate inhomogeneous current flow between the busbars. The darker parts indicate reduced emission of light and can be interpreted as interruptions or reductions in the current flow (increase of contact resistance) to the adjacent cell, so that breakage of the relevant cell interconnect may be assumed. A comprehensive evaluation of the EL images revealed cracks in 31 cell interconnects for this particular module after TC800. Other modules showed less than 10 disconnections after the same number of temperature cycles. Three of the modules showed no defects at all.

Accelerated damp-heat testing

The EL images in Fig. 4 show an example of degradation behaviour of a c-Si module taken after 1000, 2000 and 3000 hours of

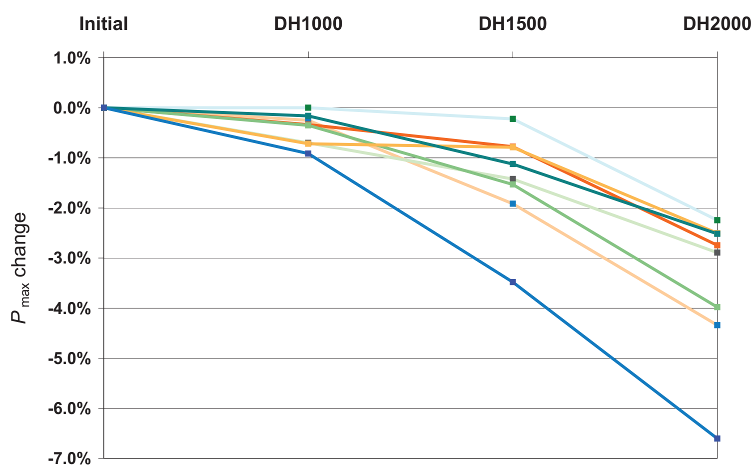

Figure 5. P_{max} change for extended damp-heat testing of eight modules from a production lot of the same type.

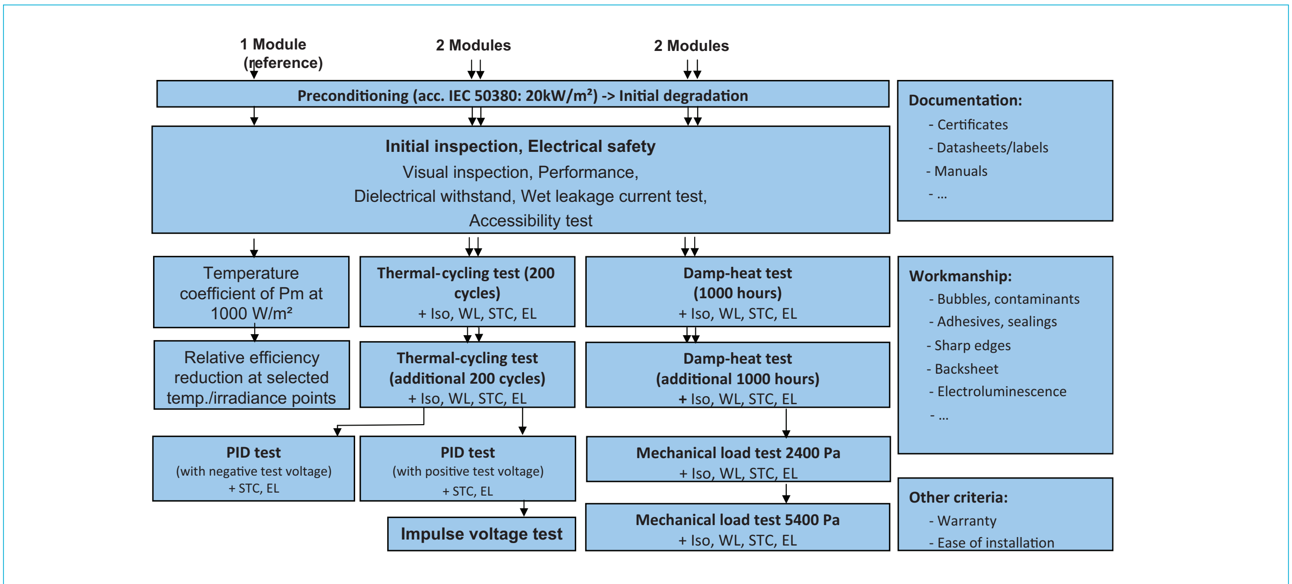

Figure 6. Test sequence of PV+Test.

Power Generation

extended damp-heat testing. Changes in EL records were mainly observed for test durations above 2000 hours. The dark areas around the cells indicate inactivity possibly caused by corrosion and water vapour diffusions across the spaces between cells. This finding is also reflected in the measured power degradation of –1%, –4% and –28%, respectively, for the intermittent measurements.

The finding that material degradation is accelerated after 2000 hours of damp-heat exposure was confirmed in a second test series, in which eight modules of the same type and from the same production lot underwent 2000 hours of damp-heat testing. This test run investigated the variations in degradation for identical test samples. Fig. 5 shows the power degradation curves resulting from intermittent measurements after 1000, 1500 and 2000 hours. For standard damp-heat testing, the spread of data points lies between 0 and –1%. The total spread increases with testing time, however, and reaches 2% after 2000 hours (seven modules), with one module showing a higher degradation.

Taken in isolation, the results of the extended damp-heat and temperature-cycling tests offer no particular gain in knowledge, since, as already noted, they bear no relationship to the actual lifetimes of the modules. On the other hand, these results are valuable if they can be evaluated by benchmarking against other products. Of course, PV modules that yield good results in the extended tests pose a lower risk of either an early failure or a failure to achieve the desired lifetime.

Benchmarking tests provide reliability and reduce the risks of failure

Previous applications of quality assurance systems through tests and inspections in the production of PV modules have indicated the following basic weaknesses:

- IEC tests alone are not sufficient for reliable predictions of lifetimes. Only expanded ageing tests will increase the store of knowledge through comparisons of different PV module types.
- Given the changes in materials and processes, as well as deficient quality in production, the quality of all manufactured modules does not always correspond to the quality of the certified product. Nor can this correspondence be ensured through intensive inspections during production.

These weaknesses can be redressed through methods of market observation, and more stringent (expanded) tests and comparative assessments, since manufacturers can gear themselves to these quality requirements.

PV+Test established as the benchmark for PV modules in the market

A benchmark test developed by TÜV Rheinland and Solarpraxis – the PV+Test – offers a suitable supplement to quality assurance and implementation, in particular for informing the end consumers (Fig. 6). Unlike the certification tests, the PV+Test is performed on modules purchased on the market. Since the number of such modules sampled will of course be very small, the manufacturer must establish 100% quality assurance in production as much as possible, in order to avoid the risk of subsequent failures.

Figure 7. Test mark of the PV+Test.

> "Unlike the certification tests, the PV+Test is performed on modules purchased on the market."

The PV+Test already takes into account the extension (doubling) of the damp-heat IEC test to 2000 hours and of the temperature-cycling IEC test to 400 cycles, in accordance with the ageing requirement explained above. The test conditions are therefore more stringent than in the IEC test. Other tests necessary for non-disrupted system operation, such as a potential-induced degradation (PID) test with positive and negative voltages, are added. Finally, the ease of assembly is evaluated as well as the data sheets and assembly instructions.

If agreed to by the manufacturer, the results of the PV+Test are published in the two professional journals *Photovoltaik* and *PV Magazine*. This system leads to a 'best-of' list, providing a good basis for planners, installers and investors for estimating quality, since it contains high-quality, marketable products. The quality of the published modules is also indicated by the fact that nearly 50% of the manufacturers do not regard the test results as meeting their own demands and therefore have not agreed to publication.

From the high-quality PV module to the professional and suitable PV system

Not only is the quality of the PV modules important, but also the quality of planning and installation of the overall system poses high risks for long-term protection of profitability. However, the influential factors for the financial risk are not limited to the technical- and safety-related risks. The risk assessment of photovoltaic projects must also include, as well as the political risks, an evaluation of the location regarding on-site risks, and an evaluation of the logistical risks in connection with the installation of the system (Fig. 8). The totality of these risks associated with the PV project are essentially borne at first by the project developers and the investors.

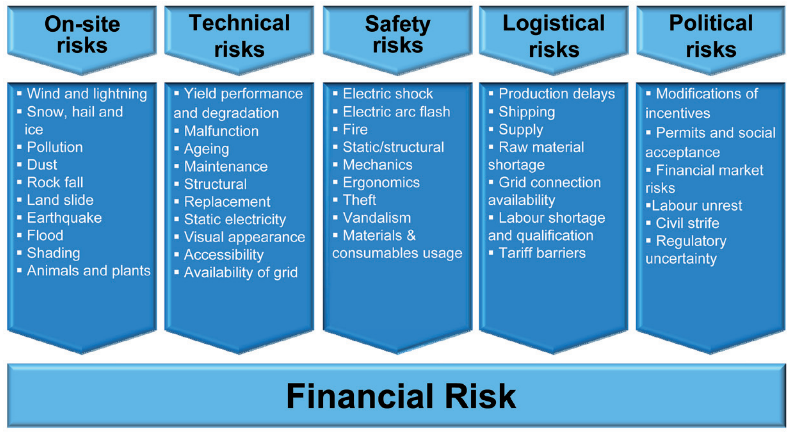

Figure 8. Types of risk.

To understand the distribution of risks and the previous quality-assurance measures, it is helpful to first look at the different motivations of the players in the project and market in terms of the required or accepted quality levels.

Module manufacturers are interested in placing their products on the market with manufacturing costs that are as low as possible and at prices that are either as high as possible or – in difficult market phases such as the current one – at least reasonable. In the long term, the margin must be such that research and development can be financed along with constantly improved quality control, as well as allowing capacity to be expanded and production processes to be optimized. Especially crucial for quality at the module manufacturer's end is that the number of complaints and warranty cases needing to be dealt with is as low as possible. High complaint rates pose a serious problem not only for the financial position of the company, but also for the reputation of the brand. Moreover, returns from the market cost many times the price of quality improvement in production. There is also the desire to position the company in a positive way among competitors through unique selling points. Besides technological leadership (concerning efficiency, for example), statements on quality and verification of quality are also regularly mentioned in this regard.

Wholesale dealers are very often involved in warranty processing. In the event that they are importing the modules themselves into the EU, these dealers will also be affected by product liability. Some established wholesale dealers have therefore developed strategies for lowering risks and for checking quality. These can range from auditing the manufacturers to taking random performance measurements and carrying out visual inspections or EL imaging for micro-crack and cell fracture detection. Test procedures, including ageing tests in climate chambers, are already being performed to some extent: these tests are conducted partly by the wholesale dealers and partly by test centres on behalf of the wholesale dealers.

To the extent that they procure the modules or import them themselves, **installers** generally do not have the resources for testing quality. They must therefore resort to other sources of information, such as the PV+Test when selecting high-quality modules, and to any possible long-term experience.

Engineering procurement construction contractors (EPCs) are subject to higher risks regarding system quality and any stated assurances as to the energy yield, and should therefore have an interest in high-quality components and qualitative conformance. At the same time, experience has shown that serious errors in planning and installation affect photovoltaic plants to varying degrees. In the best-case scenario, these errors will result in only the consequential costs of rectifying the defects. The worst case, however, may involve high material damage or even personal injury. For this reason, inspection of the plant by a third party is often required.

Investors generally bear the highest risk in the long term and therefore have a strong interest in high system quality. Of course, given the lack of knowledge and experience in this market segment, not every investor

(a) (b)

Figure 9. Damage to a PV system: (a) from ground subsidence; (b) from fire.

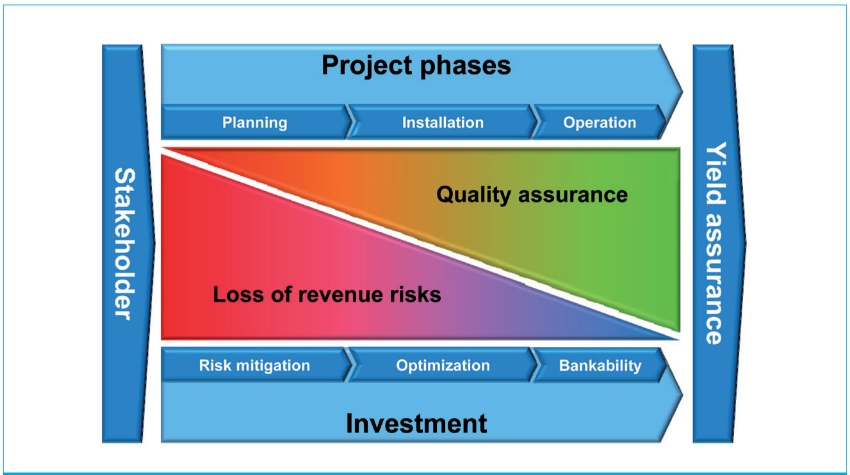

Figure 10. Quality assurance for PV power plants.

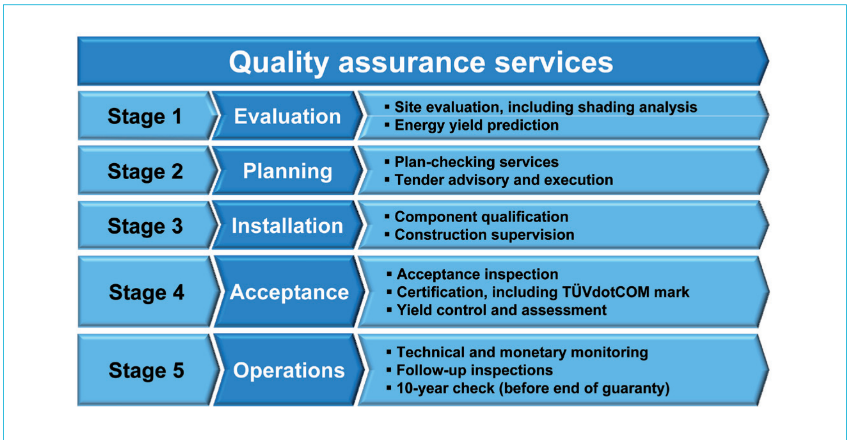

Figure 11. PV power plant inspection/TÜVdotCOM certification of a PV power plant.

can have an overview of the risks. For example, performance guarantees by the manufacturers alone are no guarantee that the expected return on investment will be realized. Since the systems are often planned and set up under considerable time pressure, the installation quality of each system again poses a high risk potential. Moreover, the striving towards the absolute minimum price at the cost of quality cannot be fully offset by PV insurance policies. The latter can be cancelled by the insurance company following damage claims or at the end of a minimum term. In the case of systems experiencing serious defects it must therefore not be assumed that the desired return on investment can be achieved in the long term. In this event, too high a loss may therefore be incurred by the investor. Given this overall situation, each investor is emphatically advised to bring in a third party to accompany the project. With its international network, TÜV Rheinland naturally has an outstanding reputation in this service and is generally recognized by all project parties.

Banks focus primarily on the credit standing of the credit receivers and on the cash flow of the PV power plants. The investors are themselves responsible for their expectations of return. Nevertheless, the banks require a wide range of technical tests and verifications to be performed. While certain banks are content with some basic information, others maintain a 'white list' as a positive list for components or EPCs. They partly comprise a considerable number of preliminary tests or tests accompanying the implementation of the PV system.

Insurance companies more or less safeguard the profitability of the PV power plants, depending on the insured risks. The quality of the components and of the installation of the PV plant is therefore vitally important. After all, high payments will still be due if the yield is low or if defects and system downtimes occur. At present the insurance companies are complaining about an exorbitant increase in damage cases attributable to inferior-quality components or faulty installations.

From bankability to insurability

As expected, the notion of bankability focuses on the role of banks, with the following definition being comprehensively applied: a bankable PV project (the set-up and operation of a PV system) requires diligence in legal, technical and economic matters to ensure the success of the project. However, there is no common understanding of the term 'bankability,' nor is there a universal standard applied. Bankability of course extends from the PV system itself to all component manufacturers and EPCs. Part of this overall bankability idea, pertaining exclusively to the banks themselves, concerns technical bankability, in the assessment of which TÜV Rheinland can be an excellent partner.

In the future, the quality assurance system resulting from the consideration of technical bankability will be largely driven by the insurance companies, since the remaining technical risks will be covered by insurance companies, leaving only a calculable risk for the bank.

Module tests for technical bankability

For the module types used, initial tests that generally go beyond the IEC tests may be required. TÜV Rheinland offers a standard procedure that can be adapted at the request of banks and investors and which should be regarded as a preliminary qualification in advance of definite projects. In this regard, factory inspections are often required as well.

Figure 12. Infrared inspection to detect hot spots.

Alongside the PV projects or large-scale PV power plants, sample testing is also possible, either in planning or during implementation. The latter deliberately dispenses with time-consuming tests in the climate chambers, so that the results can be made available very quickly during the project – for example, within two weeks. These tests present a good opportunity for quality control, since material combinations of modules from the production lots that will be actually installed in the PV system can be tested. This significantly increases the informativeness of testing. A reasonable scope of testing is generally reckoned to be power determination, light-soaking for determining light-induced degradation (LID) and low-irradiance performance for validating simulation computations of the energy yield. EL imaging allows the detection of micro-cracks and cell breakage, as can occur in improper manufacture or during transport. Electrical safety can be briefly checked by insulation tests and wet leakage current tests. Testing the modules for PID can help avoid subsequent power losses that might otherwise result from interconnections of the modules as strings, depending on the inverter topology and earthing concept. Finally, hot-spot tests, gel-content tests and rip-off tests may be added on request.

In all these tests the power determination for a suitable number of PV modules (depending on the system size) is extremely important, since the actual performance levels of the modules often do not correspond to the guaranteed performance.

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System checking

The high quality of modules and other components on its own is no guarantee of the economical operation of a PV plant, since professional planning and proper installation are also crucial. Power plant inspections are especially indispensable for large PV power plants. Depending on the desired scope, these inspections can take place during the entire project – from the planning phase and the monitoring of construction during installation, to the monitoring of the plant in the operational phase.

In the evaluation and planning phase, defects that are only rectifiable at significant cost later on can be avoided by verifying energy yield computations, performing a site evaluation (including shading analysis) and checking the plant specifications. The planning review of outdoor plants requires a geological survey and static verification for the foundations of the mounting systems and statics. These documents must be checked for plausibility. The same applies to the optional construction monitoring, which can detect problems early enough for possible rectification without extra costs. Experience shows that most errors are made in carrying out the construction work. Spot-checking of module performance in the laboratory with high measurement precision and with optional construction monitoring is an important element of the installation phase.

The technical plant inspection includes the following:

- Safety-related inspection
- Comparison with the specification
- Verification of the functioning of the entire plant
- Power measurements of single strings
- Infrared inspections of module and generator connection-box samples
- Measurements of the layer thickness of coated mounting parts

The economical operation of a PV power plant requires plant monitoring, which can be performed by a service provider such as TÜV Rheinland. Regular inspections of the plant and plant safety – as well as inspections that are due before the end of warranty periods, product warranties or stages in performance warranties – form an often-neglected part of quality assurance.

Summary

Quality need not be expensive; on the contrary, suitable quality assurance pays off and leads to a higher return on plant investment. It is reasonable to use an integrated concept for preventing multiple measurements and qualifications. This concept begins at the production site of the modules and other products, and must focus on the quality of each individual manufactured module, in addition to certification. A regular inspection of PV modules on the market in the context of benchmarking (PV+Test) will yield information about achieved quality levels which will be understandable by installers and end consumers. While benchmark information on expanded ageing tests (damp heat and temperature cycling) provides no concrete details about the lifetimes of PV modules, it does help in minimizing the risks and in attaining higher lifetimes of more than 25 years.

Besides PV module qualification, PV plant qualification is extremely important. In the foreseeable future, the insurers – as well as the investors and professional operators – will impose requirements aimed at significantly higher quality levels. Plant monitoring and maintenance must be given considerably more importance; this, of course, also applies to small power plants. A comprehensive quality assurance system must also clearly cover transport and logistics, both in the worldwide flow of goods and at the construction site. The coordination and reliable documentation of module data during production, and stress documentation during transport to the construction site, can verifiably establish the condition of the product up to the time of installation and thereby avoid the problem of repeated multiple qualifications.

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