On-site PID testing

Power degradation | Potential-induced degradation (PID) is still one of the main reasons for unpredictable power losses in PV power plants. Volker Naumann, Nadine Schüler and Christian Hagendorf of Fraunhofer CSP and Freiberg Instruments present an approach for quick on-site PID testing of mounted PV modules, allowing PID diagnosis and prognosis of PID-related yield losses

In the last few years many European plants with c-Si solar modules which have been in operation for a couple of years have become suspicious that they may be affected by PID [1]. The most frequent type of PID in c-Si modules is the shunting type [2], also called *PID-s*. When it is suspected that PID is responsible for some observed power loss, electro-optical inspection by infrared thermography (IR) or electroluminescence (EL) is usually performed, in order to detect or exclude the occurrence of distinct PID signatures (e.g. checkerboard pattern) along complete module strings. Alternatively, the measurement and comparison of the string voltage level at the maximum power point under weak irradiation is used as an indicator for PID-s.

All these methods are indirect and therefore leave room for interpretation; in other words, the findings cannot always be clearly and unequivocally attributed to PID. Furthermore, these methods are not able to predict the susceptibility of modules to PID when as yet no measurable power loss has occurred. For this reason, modules are dismounted to seek further proof of PID sensitivity at testing institutes. Laboratory PID tests are usually carried out in large-scale climate chambers in accordance with the technical specification in the IEC TS 62804-1 standard [3]. This procedure is very time-consuming and incurs a high cost in relation to dismounting, shipping and testing. It is therefore much more attractive to perform PID tests on-site, following the set-up and procedures used in the laboratory, without any need for dismounting. Moreover, up until now it has not been possible to satisfactorily predict the rate of recovery, which is often the intended parameter to be boosted by retrofitting specific recovery devices.

Design of the on-site PID test

The on-site (outdoor) PID test procedure is simple in design for easy handling; it is quick and reliable, but also not too far removed from the existing test standards that are commonly used in the laboratory. The only existing PID test standard – the IEC 62804-1 technical specification – is used as a starting point. Since the severity of the outdoor PID test method should not depend on the surface conductance of the module glass (influenced by dust, dirt, humidity), the stress method (b), namely "contacting the surfaces with a conductive electrode", of IEC TS 62804-1 is adopted for outdoor testing. This consists of a conductive foil on the front surface of the module and an applied voltage corresponding to the module rated system voltage between the grounded conductive foil and the cells. Typically, this test takes 168 hours at 25°C, but it is also permissible to apply higher temperatures to accelerate the PID process. Thus, the two crucial parameters of an accelerated PID test are: 1) a high voltage between the glass surface and the cells to incite leakage currents; and 2) an elevated temperature to accelerate the degradation.

> "The on-site PID test procedure is simple, quick and reliable"

Characteristic	IEC TS 62804-1, stress method (b) [3]	PID outdoor test	Remarks
Application of high voltage	Module rated DC system voltage between a conductive foil on the total area of light-facing surfaces and framing, connected with the ground terminal of a DC voltage supply, and cells (module connectors).	Module rated DC system voltage between a metal sheet on the light-facing module surfaces, connected with the ground terminal of a DC voltage supply, and cells (module connectors).	Neither accounts for module-level designs intended to mitigate degradation by reducing leakage current pathways to ground; the PID sensitivity of module-level designs without a metal frame might be overestimated.
Temperature	Module temperature of 25± 1°C, or alternatively 50°C or 60°C if greater acceleration is desired.	Module temperature of 85°C in the module area that is covered with the metal sheet.	
Humidity	Dry (RH < 60%).	Dry and clean module surface; RH is low as a result of external heating and heat insulation.	For the PID outdoor test, the humidity level can be neglected because of intentional grounding of the module surface.
Irradiation	Dark condition due to metal foil on the total area.	Dark condition due to heat insulation.	
Duration	Dwell duration: 168h.	Test duration: 4h.	
Assessment of power degradation	Maximum power determination as specified in section 10.2 of IEC 61215:2005 – before the voltage stress test, and between 2 and 6 hours after the test.	Continuous recording and display of in-situ measured forward current in the dark at $1/3V_{oc}$, and of dark *I–V* curves every 5 min.	Forward current is used as an indicator; an electrical model is used for estimating the power loss.

Table 1. Comparison of the proposed PID outdoor test with stress method (b) in IEC TS 62804-1

For the outdoor application, the grounding on the front surface and the increase of the module temperature are realised by means of a thin metal sheet and a heating pad. In a laboratory PID test, using the stress method (b), both the temperature and the high voltage level are laterally homogeneously distributed over the module area. For an outdoor PID test, this cannot be accomplished with a reasonable amount of effort and power consumption because of the heat losses at the edges and the rear of the module. For this reason, a heating pad and a metal sheet for grounding that cover only approximately half of the area of a standard 60-cell module are used; these can then be applied to several different module sizes. In consequence, only a fraction of the cells in a module is subject to PID stress, but since the in-situ measurement of the electrical module parameters is very sensitive to PID, the result can be extrapolated to the total module area.

It has been determined from relevant studies that the most sensitive electrical parameter is the forward current (the current flowing through serially connected cells with a forward bias) under dark conditions. A voltage equal to one-third of the open-circuit voltage is chosen as a good trade-off between achieving high sensitivity to PID and not demanding the measurement device to handle overly high forward currents. (For reference, the increase in the forward current due to PID is visualised in the *I–V* curves in Fig. 3, presented in a later section.) Table 1 presents a summary of the design of the outdoor test, along with a comparison with the established stress method (b) of IEC TS 62804-1.

Description of the test set-up

A prototype test set-up, based on the general design above, was constructed. The wiring scheme is illustrated in Fig. 1, which shows the equipment for heating, application of high voltage and measurement of the forward current.

With the current test set-up, 24 Si cells of a 60-cell module were subjected to high PID stress by grounding the front glass surface and simultaneously heating the module area, while a high negative voltage was applied to the cells. The set-up and measurement principle were tested outdoors on two different 60-cell modules: one freestanding module installed on a test field and one module deployed in a large-scale PV power plant. Fig. 2 shows the prototype of this outdoor PID test set-up, attached to the Si solar modules for the first tests.

The module used for the outdoor test on the test field was specially manufactured at Fraunhofer CSP and equipped with eight thermocouples; this arrangement makes it possible to determine the temporal and spatial distribution of the module temperature. It was discovered that the design and application of heat-insulating materials are crucial for the PID outdoor test, since a relatively high temperature of 85°C needs to be reached within a short time and homogeneously maintained over the tested module area. Therefore, in addition to the insulating blanket (Fig. 2(b)) on the front side of the tested module, the rear side is lined with heat-insulating foam pads.

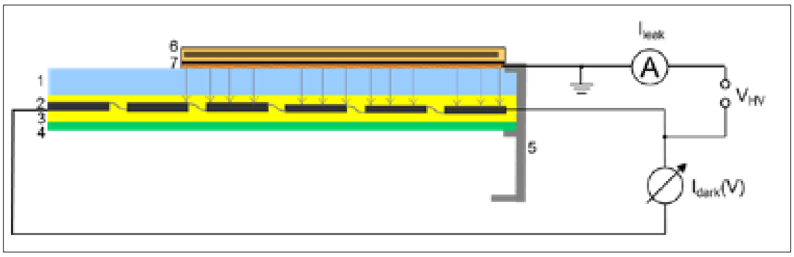
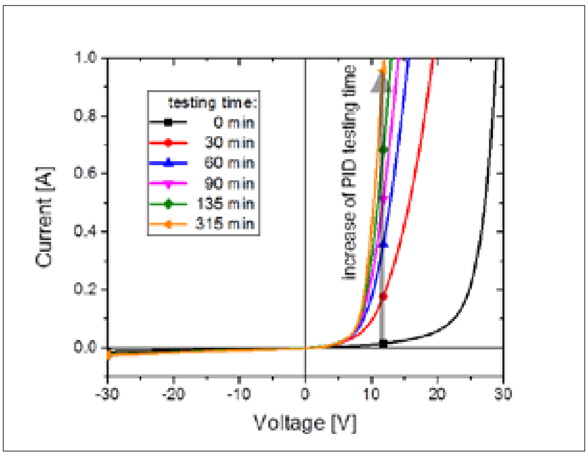


Figure 1. Wiring scheme for the PID test (1: module cover glass, 2: cells, 3: encapsulation polymer, 4: backsheet, 5: module frame, 6: heating pad, 7: metal sheet for grounding)

(a) (b)

Figure 2. (a) Grounding metal sheet (silver) and heating pad (orange) attached to a freestanding module on a test field; (b) the same set-up, covered by the heat-insulating blanket (black), deployed in a large-scale PV power plant



Initial results on the feasibility of on-site PID tests

Laboratory testing

PID tests were initially performed using the prototype test set-up in the laboratory on nine 60-cell multicrystalline Si modules from different manufacturers with different PID sensitivities. These tests showed that the test set-up was able to clearly demonstrate the PID sensitivity of solar modules by means of an in-situ measurement of the forward current. Fig. 3 shows the behaviour of the dark *I–V* curves after increasing PID test durations for one of the modules at a temperature of 85°C and a voltage of –1,000V applied to the cells. It can be concluded that a test duration of less than one hour is sufficient for differentiating between PID-resistant and PID-susceptible modules. With the forward voltage of $1/3V_{oc}$, a very high sensitivity of the current with respect to PID is achieved; this corresponds to 12V for this particular module (the arrow in Fig. 3).

In the PID test run with all nine modules, the current is measured under dark conditions at a forward bias of 12V, with a narrow time interval of one minute between two measurement

Figure 3. Dark *I–V* curves, acquired in situ, of a 60-cell module (V_{oc} = 36V) when 24 cells were subjected to a PID stress of –1,000V at 85°C, showing the evolution of PID with time

"The test set-up was able to clearly demonstrate the PID sensitivity of solar modules by means of an in-situ measurement of the forward current"

points. This results in the generation of the curves for the forward current as a function of time over the entire test duration.

Fig. 4(a) shows the curves for four representative samples that were measured in the laboratory in identical conditions (ambient temperature 22°C, module temperature 85°C, voltage at the cells –1,000V with respect to the grounded frame and glass surface). The modules exhibit clearly different behaviours; while module C does not show an increase in forward current at all, the other three do exhibit an increase.

The leakage current that is measured in the high-voltage circuit of the test device represents the conductivity of the module encapsulation materials under the influence of high-voltage stress. This current is recorded in the same time interval as the forward current and provides additional information about the stress that the cells within the module have been exposed to. The leakage current curves are shown in Fig. 4(b). Note that modules A2 and B, for example, appear to exhibit approximately the same PID sensitivity, given the shape of the curves of the forward current over time (Fig. 4(a)). The leakage current of module B, however, is more than double that of module A2; this strongly indicates that the cells in module A2 have in fact a higher PID sensitivity than the cells in module B, which features a higher conductivity of the encapsulation materials, leading to a higher voltage stress level for these cells. This can be explained by the so-called *voltage divider model* [4].

The measured forward currents after the completion of the tests demonstrated the same ranking of PID sensitivity as that corresponding to the power measurements and EL images used as a reference for assessing the PID sensitivity. The EL images that were acquired for modules A2 and C are shown in Fig. 4(c) and 4(d). In the case of the PID-sensitive module A2, it is clearly visible that only the cells that are located below the grounded metal sheet and below the heating pad (see Fig. 2) suffer PID. The basic functionality of the PID outdoor test is thus validated.

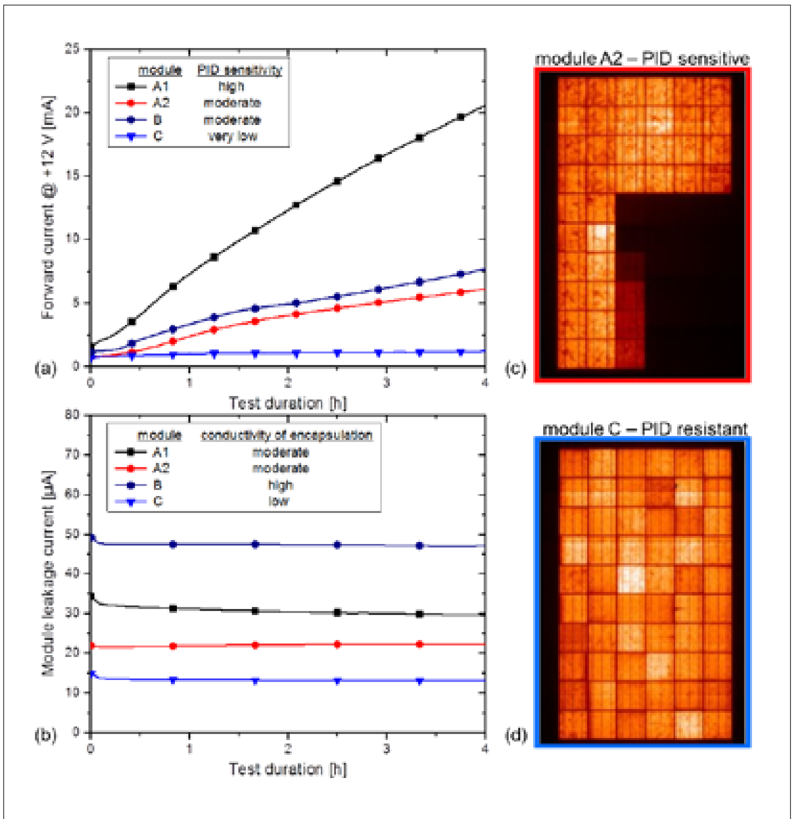


Figure 4. (a) Forward current and (b) measured leakage current for four different modules subjected to the outdoor PID test procedure; EL images acquired after the PID test for (c) the PID-susceptible module A2, and for (d) the PID-resistant module C

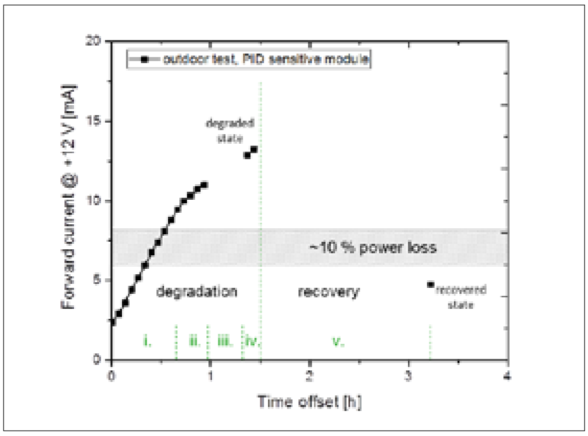


Figure 5. Forward current and measured leakage current of a module undergoing the PID test procedure in real outdoor conditions at a PV power plant

Outdoor testing

The test set-up was used to demonstrate the measurement principle under real outdoor conditions in an operating PV power plant (see Fig. 2(b)). The test was conducted on a partly cloudy day, with strong winds (gusts up to 30km/h) and rain showers, at ambient temperatures of 16–19°C. The test temperature at the module surface was 85°C and the high voltage (–1,000V during the degradation phase, and +1,000V during the recovery phase) was applied to the cells with respect to the glass surface grounded by the metal sheet and grounded module frame.

The graph of the recorded forward current as a function of test time is shown in Fig. 5. It can be seen that the initial increase of the forward current is even steeper during the first 40 minutes, indicating a very high PID susceptibility of the module installed in the PV power plant. The estimated threshold of a 10% power loss due to PID is already exceeded after approximately 30 minutes of PID stress time.

It should be noted that the outdoor test measurement shown in Fig. 5 was divided into five phases (marked in green) for the sake of studying the dependencies of the PID severity (and the leakage current) on module temperature and polarity of the high voltage. The five phases of the outdoor test that can be distinguished are:

i. PID testing at a constant temperature of 85°C.
ii. PID testing during the cool-down.
iii. Heating up to 85°C.
iv. PID testing at 85–90°C.
v. Recovery and short measurement of forward current after recovery.

By means of the applied reversed polarity (cells at +1,000V with respect to the grounded module glass) at the end of the outdoor test, it was demonstrated that the module could be recovered to almost its initial state within a short period after a PID test.

Future developments

Within the framework of the research project 'PID-Recovery', the on-site PID test device will be adopted for routine measurements; the PIDcheck test device (Fig. 6) will be used to perform PID tests in four different solar parks in Germany. A special emphasis will be placed on an investigation of the recovery process. The behaviour of the estimated module power loss, which can be calculated from the dark *I–V* curves acquired during PID and recovery tests, will be used for extrapolating the future electricity yield, both without and with a retrofit of the recovery methods. With this set-up, the cost effectiveness of PID countermeasures, such as changing the modules or retrofitting recovery devices, will be assessed.

Figure 6. Control unit of the on-site PID test device 'PIDcheck' from Freiberg Instruments, due for market introduction in summer 2018

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