# All about PID – testing and avoidance in the field

**Module degradation |** Potential-induced degradation can cause significant power loss in modules if the appropriate precautions are not taken. In the first part of a new series in *PV Tech Power* on module failure, Peter Hacke and Steve Johnston assess the current state-of-the-art in detecting, avoiding and mitigating the worst effects of PID

Potential-induced degradation (PID) in PV modules is activated by the stress of system voltage and the resulting small but continuous current transfer between ground and the cell circuit. With system voltage extending from 600V to 1,000V and 1,500V or greater, the electric field between cells within the series string of interconnected modules and ground is an increasingly stressful driving force for PID.

The term PID can imply a number of various degradation mechanisms in PV modules driven by voltage potential. These include the short-circuiting of the diode junction of the cells, which in conventional cells exists a few tenths of a micron below the front plane of the cell surface. This mechanism is referred to as PID-shunting (PID-s). It is PID-s that has garnered the most attention because it is the PID mechanism that has caused the greatest power loss, with the potential to affect most conventional crystalline and multicrystalline cell module types, which have over 80% market share today.

There are a number of reports of PID-s occurring in the field. PI Berlin has published locations where it has diagnosed PID-s around Europe [1]. These locations include the hot, generally sunny climates of Andalusia in southern Spain and the wet, rainy and cool climates of Belgium. Both elevated heat and humidity are environmental factors that increase PID rate. PID is however not only observed in extreme climates – it has also been observed in the more moderate climates of New York State, Italy and Germany. Degradation has at times been reported to be severe in these locations. For example, power loss of more than 40% of module nameplate power is not uncommon.

The PID-s mechanism occurs when the cells in the module are at negative potential with respect to ground. Positively charged sodium ions in the glass, encapsulant, or cell surface are transported by the electric field due to the system voltage potential toward the light-absorbing active layer of the cells, causing shunting of the cells where the sodium diffuses into defects in the cells (Figure 1). The electric field in the glass is enhanced by high humidity, soiling and rain, which increases surface conductivity and puts the glass face at equipotential to the grounded frame. On the other hand, higher temperature and dry conditions will usually make the module surface less conductive, but will make the packaging (glass, encapsulant) more conductive. This enhances the transport of sodium ions through the front glass near the grounded module frame or mounting points.

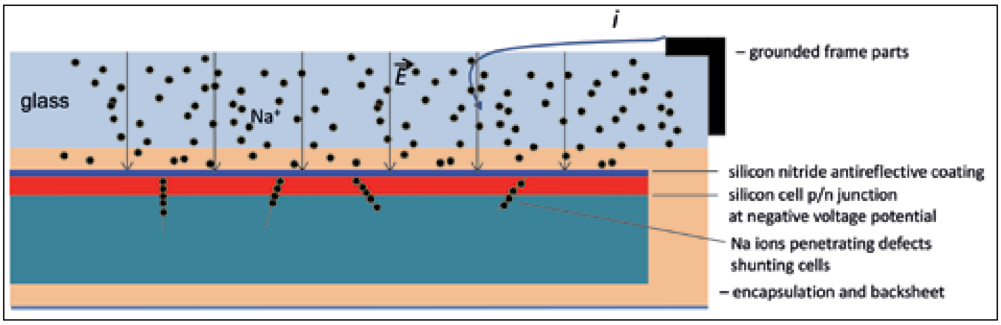


**Figure 1. Schematic of module cross-section containing cells at negative voltage potential. Na+ ions are transported by the electric field between the glass face and the cell, which may eventually diffuse into defects in the cell, shunting the p/n junction, causing PID-s**

System configurations where PID-s can occur include where the positive end of the module string is tied to ground or, much more frequently, in the negative potential side of module strings in ungrounded PV systems using inverters without isolation transformers. Additionally, higher than normal voltage potential stress can be exerted on the modules when the system is at open circuit; for example, when modules are mounted and connected to one another in strings, but not being maximum power-tracked. Because open circuit voltage (Voc) is higher than the maximum power voltage (Vmp), module strings in open circuit lead to greater voltage potential between ground and at least some of the modules in string than during normal operation. Also, if the modules are connected to one another into a string, but neither terminal of the string is connected to anything, then the voltage in the string may float in an uncontrolled manner, leading to the potential for higher PID stresses on the modules.

Besides PID-s, other PID mechanisms include delamination, where there is significant Na migration to the cell surface, which has been associated with reduced adhesion, and bubble formation because of gaseous products of electrochemical reactions driven by the high voltage and resulting current transfer [2]. Other cell designs and constructions (including thin-film modules types) have also exhibited various effects of system voltage, including PID-s and corrosion [3]. Another well-documented PID mechanism is polarisation, which in the past affected certain high-efficiency crystalline silicon cell types in positive strings (where the negative terminal of a string is connected to ground) [4].

Module makers can increase module resistance to PID. Commonly implemented methods for doing so include adding layers or optimising the sodium barrier properties in the deep blue-colored antireflective coating (silicon nitride) deposited on the cells and the use of higher quality, electrically resistive, polymeric encapsulants within the module package. Higher quality glass offering higher electrical resistivity and other methods to enhance the electrical isolation of the glass face may also be employed. A combination of some of these PID-s-resistive features is frequently implemented, and is in our opinion preferable for improving resistance to various PID mechanisms.

## PID testing

Testing methods to evaluate PID susceptibility have recently been developed. IEC Technical Specification 62804-1 contains standardised PID test methods for crystalline silicon modules. The protocols contained therein are for evaluating susceptibility to polarisation and PID-s, which are the mechanisms most likely to reveal themselves in the relatively short term in the field. While this IEC technical specification does not contain pass/fail criteria, the stresses and the levels contained therein were chosen to be relevant for the sensitivity of modules to these PID mechanisms in the natural environment.

IEC Technical Specification 62804-1 contains two test methods. In both cases, the module power leads are shorted together, and these connected leads are biased at the rated system voltage (Vsys) for their rated polarities (-Vsys and/or + Vsys), two samples each, for a specified duration (Figure 2). The grounding of the external surfaces differs depending on the test method. Either just the frame is connected to ground (relying on damp heat to achieve a conductive adsorbed water film on the glass), or the frame and the glass surface are grounded with a foil. The test method details are as follows:

**(a) Testing in damp heat using an environmental chamber:**
Module temperature: 60°C; chamber relative humidity: 85%; dwell duration: 96 hours.
Temperatures of 65°C and 85°C providing higher stress levels are given as alternatives.

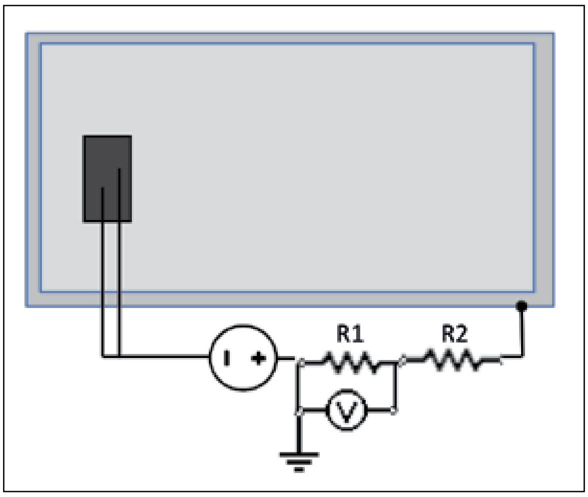


**Figure 2. A configuration for testing for susceptibility to PID. The module leads are shorted together and negative voltage potential is applied to them. Current transferred to ground is measured here by sensing voltage over a resistor in a voltage divider network that is used to protect the voltage meter from high voltage**

**(b) Contacting the surfaces with a conductive electrode (metal foil):**
Module temperature: 25°C; relative humidity: less than 60%; dwell duration: 168 hours.
Temperatures of 50°C and 60 °C providing higher stress levels are given as alternatives.

Neither stress test completely reproduces all the factors that a module would experience that influence the PID-s rate in the field; for example, the tests are performed in the dark. It has been found that light exposure prior to application of a PID stress test can make a module more susceptible to PID-s [5], whereas light exposure during application of PID stress reduces the extent of PID-s [6].

The test methods (a) and (b) each have advantages and disadvantages. Method (a) applies actual stress factors of the natural environment: heat and humidity that can diffuse through the module backsheet and encapsulant. Use of actual environmental stresses tests their direct effects on PID, usually increased bulk conductivity of the module package. Method (a) also evaluates the effect of the intrinsic conductivity of the glass surface, which can vary depending on factors such as the use of antireflective coatings. Because it depends on adsorbed humidity to increase the conductivity of the module face, it has also been found to correctly differentiate solutions used to mitigate PID such as rear insulating mounting rails instead of a module frame [7].

The Al foil method (b) has the important advantage of being simpler to implement, not requiring an environmental chamber. Also, the application of the foil on the module surfaces leads to equipotential of the surface and the grounded module frame, as would a film of precipitation or condensation on the module surface of a conventional framed module. However, unless the Al foil test is done at one of the higher temperatures above the baseline level of 25°C, the ionic conduction through the glass and encapsulant is not accelerated in this test, despite the electric field being distributed uniformly over the module face, which activates the PID more uniformly. Modules in the natural environment of course experience much higher temperatures than 25°C.

To evaluate the field-relevance of the test methods and their ability to inform which modules may degrade by PID-s in the field, we have conducted our own tests and surveyed some module manufactures, testing labs and research institutes to find modules that degraded by PID-s in the field, but did not degrade by the 62804-1 test protocols. Our surveys have not found any such cases yet, which indicates that these proposed test protocols may be sufficient to screen for PID-s susceptibility. Admittedly, our survey may not have adequately represented hot desert or hot and humid equatorial climates. Especially for such stressful climates, the test temperatures providing higher stress levels in method (a) and (b) of 62804-1 may be considered for risk reduction. It is anticipated that one or both test methods based on those found in IEC 62804-1 will be implemented into IEC 61215, the module qualification test standard. Additionally, test methods considering the dominant PID mechanisms in thin-film modules, or modules with moisture barriers and moisture sensitive cells, will be defined in another IEC technical specification, IEC TS 62804-2. Standardised tests for additional PID mechanisms for crystalline silicon modules, such as for delamination, are also anticipated in the future. Including these important PID screening tests in standard module qualification tests will reduce the number of modules entering the market that are prone to PID-s performance loss.

## PID in the field

It has become apparent that a number of important module manufactures were not giving attention to PID-s when the issue became widely published in the literature beginning in 2010 and 2011. However, our experience is that the major module manufacturers are now giving due attention to the PID-s issue at this time, and are making conscious design decisions for achieving PID-s resistance to the extent they deem appropriate for their modules. On the other hand, there are still some module makers ignoring PID-s (as are their customers), and in such cases, the modules are more likely to be susceptible to PID-s.

There is no standard for what constitutes a "PID-resistant" or a "PID-free" module. In fact, susceptibility to PID not only depends on the module but on the field use condition. Regardless of such labels, one must ask what test was applied to evaluate the PID resistance of the modules, and the results. The test conditions applied should be compared to the IEC 62804-1 stress factors and levels, and the modules preferably should not exhibit degradation through the applied tests.

Of equal importance to the PID-resistance of the module is the quality assurance protocol of the plant where the modules are produced. The same bill of materials and processes as the design that was evaluated in PID-s testing must continue to be used. It is also necessary for companies to continuously evaluate the product coming from the production line for PID-s resistance. It is however difficult for all but the largest investors and buyers to objectively evaluate what the company is doing in this regard, but one can look for module producers that have volunteered to conduct third-party inspections of their quality assurance system, encompassing consistency in the incoming materials, manufacturing process of modules and their components, and continuous testing for the durability of the product, inclusive of PID-s.

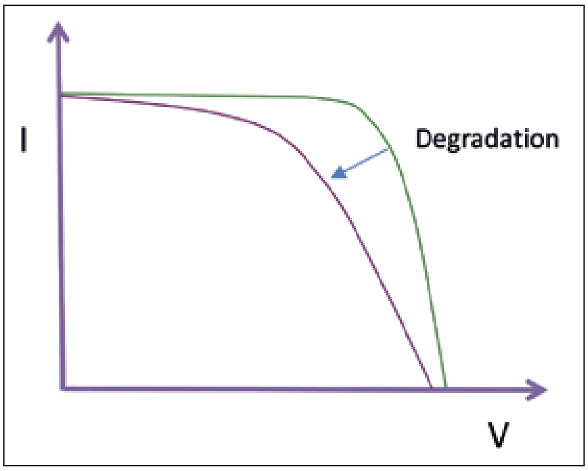


**Figure 3. Degradation of a module I-V curve under standard test conditions (25 °C, 1000 W/m2) when affected by PID-s. The maximum power point Pmax degrades because of shunting of the cells, through reduction of the fill factor. Voc is less affected, and Isc is that last parameter to degrade**

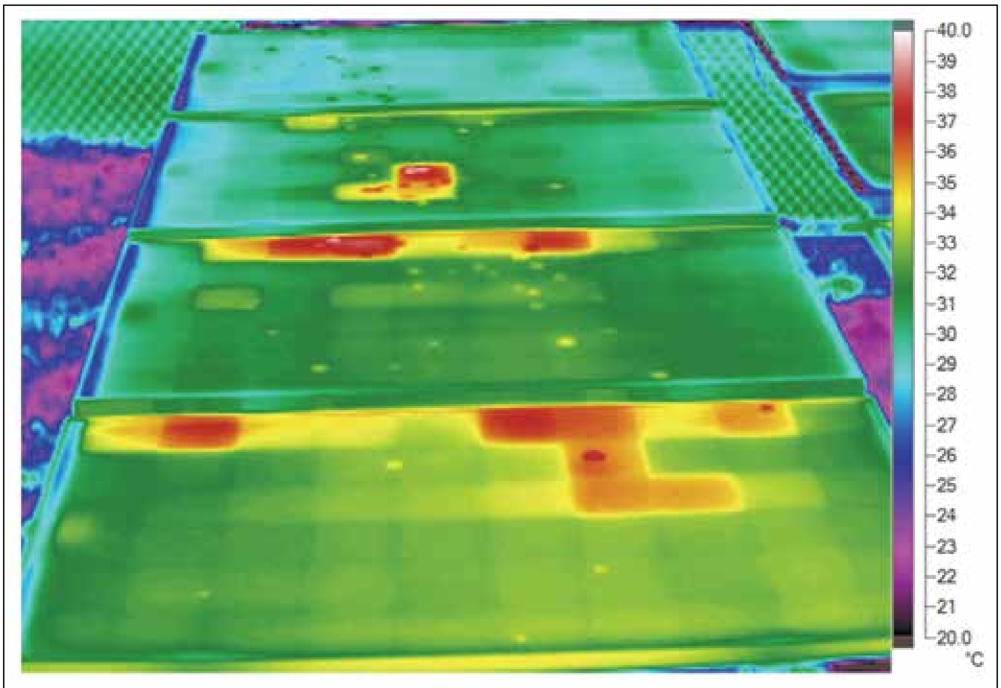


**Figure 4. Imaging by thermography is a simple method to visualise PID when there is sufficient irradiance to provide contrast. Here, various modules are imaged from above at the most elevated side of the array. PID-s is seen in the hotter cells, frequently toward the lower edge of the module as seen here, where water and soiling may accumulate that facilitates conductive pathways causing the PID-s**

How is one to know if the modules you have purchased are affected by PID-s? The effect on modules in systems is detectable if one knows what to look for. At standard test conditions (STC, which is 25°C and 1,000W/m$^2$), PID-s will first affect the maximum power point of PV modules by degradation of the fill factor (Fig. 3). Only after significant degradation will the Voc be affected. The least sensitive parameter and last to be affected is the short-circuit current (Isc). A second signature of module shunting is that the low-light (i.e. 200W/m$^2$) performance ratio degrades, and will be significantly more degraded than the performance ratio at 1,000W/m$^2$ irradiance. A newly proposed method for electrically evaluating PID-s is to track voltage versus irradiance or current under low light (Suns-Voc method), such as when the sun sets. This will also show evidence of shunting by the signature of reduced voltage under very low light conditions (where reduced voltage is a signature of PID-s), compared to unaffected modules [8].

Optical methods for detecting PID in the field or in the lab include thermography, where affected cells in all but the most degraded cells in the module appear hotter. Because of its simplicity, thermography is especially favoured for field-testing of PID-s when there is sufficient solar irradiance (for example, >700W/m$^2$ in the plane of array) to show contrast. PID-s-affected areas are essentially short circuited and display power dissipation at those places (Fig. 4, Fig 5(b)). Other optical methods include electroluminescence (Fig. 5(c)) and photoluminescence where affected cells display less emission because generated charges (either by optical or electrical excitation) are lost to the shunting in the cells. Lock-in methods for performing electroluminescence, photoluminescence and thermography in daylight on fielded modules also enable clear images of PID-s-degraded cells (Fig. 5(a) and (d)). Also, one can use lower cost, conventional optical equipment along with tents or dark boxes placed over the module to detect the cells exhibiting PID-s with electroluminescence [9].

## Dealing with PID-s

If one has already purchased PID-s susceptible modules or if one has a power plant with cells affected by PID-s, what can a plant owner do? If warrantee returns aren't an option, one must look

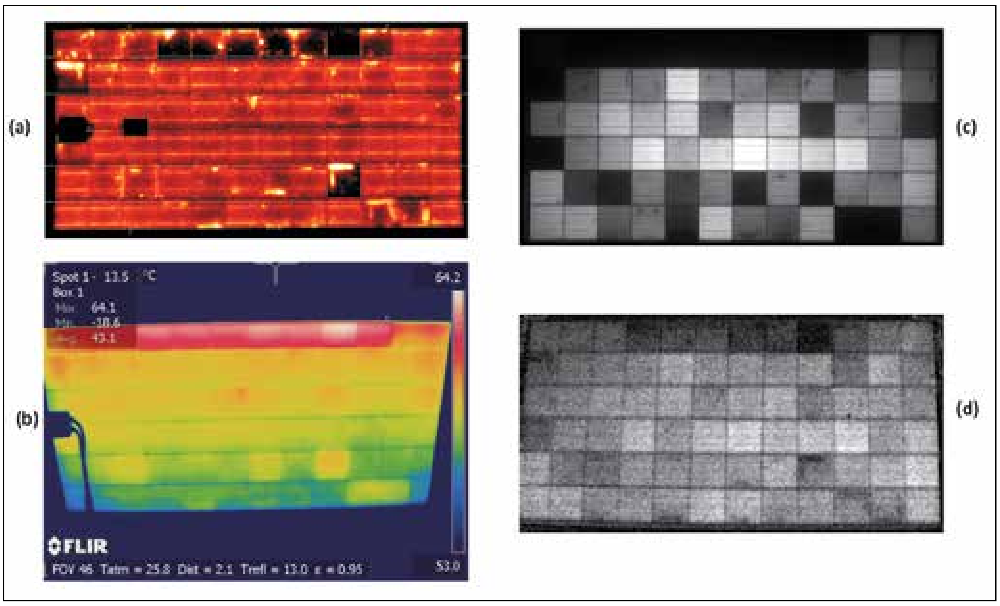


**Figure 5. A module degraded by PID-s in the field imaged by four different techniques. (a), Lock-in thermography (laboratory); (b) conventional thermography (field); (c), electroluminescence (laboratory); and (d), lock-in electroluminescence, under daylight in the field**

to other solutions with what one has at hand. Most (but not all) modules affected by PID-s exhibit an extent of power recoverability. That means that when the negative system voltage stress on the modules is removed, the power can recover with heat and time. The current understanding is that sodium driven into the cells can diffuse out of them. This can be further accelerated or the extent of recovery increased by reversing the string polarity—biasing the module with the system voltage in the opposite sense, positively.

In controlled conditions using an environmental chamber, PID-s-degraded modules with over 15% of initial power remaining could be recovered to an average of 97% of their initial power value by reversing the system voltage bias in otherwise the same conditions as the degradation. However, other modules with more severe power loss could only be recovered to an average value of 59% of initial power [10]. In the case of a system on a transformerless inverter having both modules in positive and negative system voltage potential, one can reverse the position (in terms of potential) of each module in the string. For example, the module at the negative terminal of the inverter is connected to the positive terminal of the inverter; the second module from the negative terminal of the inverter is placed second from the positive terminal of the inverter, etc. Of course the modules in the part of the circuit now in negative potential with respect to ground will experience PID-s stress. Therefore, this polarity switch may need to be repeated again in the future. It has however been shown that repeated cycles of PID stress and recovery can lead to an extent of stabilisation of PID-s, where increasingly more stress is required to achieve PID-s [11].

Using a similar principle, customers have requested inverter manufacturers to supply hardware that applies positive system voltage bias on modules at night, reversing the motion of sodium ions (out of the cells) and restoring power to the PID-s-affected modules. Current transfer between the module and ground has been measured to be significant when system voltage bias is applied to the module circuit at night when there is no sun to dry condensation and rain. When the system voltage stress is exerted on the modules both night and day in alternating polarities, continually active electrochemical processes increase the risk of occurrence of other PID mechanisms. At least one major inverter manufacturer that at one time sold hardware to bias modules at night no longer does so.

Choosing an inverter topology that places all modules in a positive string with respect to ground will prevent PID-s in conventional modules. Grounded systems using inverters with transformers also remains a solution, but is becoming increasingly rare due to electric code changes, and improvements in transformerless inverter performance and cost. Inverter manufacturers and third party add-ons may offer other solutions that effectively maintain the module string in positive bias with respect to ground during operation.

Microinverters applied to individual modules in operation can serve to maintain the module at a voltage no higher than that of the individual modules. While the voltage developed within an individual module is much less than that reached in series-connected module strings, PID-s has still been observed in susceptible modules biased only to this modest voltage. PID sensitivity of modules therefore cannot be completely neglected, even when considering modules for connection to microinverters.

## Getting on top of PID

The outlook for getting PID under control is quite favourable. There have been improvements made in PID resistance of module encapsulant types that have been used for many years, such as ethylene vinyl acetate (EVA). Additionally polyolefin, ionomer and silicone may be used in the module laminate leading to higher electrical and PID resistance. Increasing electrical resistance of the module packaging is an overall favored solution for minimising the various PID mechanisms that exist. However, better encapsulants may be combined with solutions on the cell level that arrest the transport of the damaging sodium ion to the absorber layer of the cells, further improving the resistance to PID-s. Changes to the materials of the module packaging for the purpose of improving PID resistance tend to be introduced slowly and cautiously to verify that such changes don't lead to other, unanticipated failures. There is, however, a body of experience with many alternative encapsulants at this time.

The market has shown that moving to higher system voltages is economically favourable, so attention to PID will continue to be required. Test regimes for evaluation of PID mechanisms that manifest in the relatively short term (polarisation, shunting) exist, which may be applied to evaluate module susceptibility. The next stage will be inclusion of a pass/fail criterion in an amendment to IEC 61215, the terrestrial photovoltaic module design qualification and type approval standard. Consistency and quality of manufacturing is also important because small changes to the materials or the module manufacturing process can lead to changes in PID susceptibility. Many module manufacturers have PID-s under control and are making conscious decisions about making their modules durable to PID-s.

However, some manufactures and customers have not given sufficient attention to the matter and PID-s-susceptible modules can still be found on the market. Electrical and optical methods for diagnosing PID-s exist so that power plant operators can identify PID-s in their fielded systems. Cell, module and system-level solutions exist for mitigating PID-s and preventing their occurrence in the first place. The effects of PID-s can be reversed by removing or reversing the negative system voltage bias causing PID-s. Therefore solutions exist for significantly recovering the power of PID-s-affected modules.

## Authors


Peter Hacke is a senior scientist at the National Renewable energy Laboratory, Colorado, USA. He performs research and consulting for durability testing, validation and failure analysis of PV modules, inspections for root cause of module failures in the field, and accelerated lifetime testing, including for potential-induced degradation, power loss, corrosion, bypass diodes and delamination. His research interests include modelling of degradation processes of PV modules and developing new methods for analysis of PV degradation data.

Steve Johnston has a Ph.D. degree in materials science from CSM. From 1991 to 1993, he worked at integrated-circuit manufacturer Texas Instruments. Since 1996, he has been with the National Renewable Energy Laboratory. His work and research interests have included minority-carrier lifetime by photoconductive decay and time-resolved photoluminescence, deep-level transient spectroscopy and imaging techniques that include photoluminescence, electroluminescence and lock-in thermography.


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