Understanding PID: Improving the performance of large PV systems

Performance | Potential-induced degradation (PID) has emerged as an issue of concern in the last decade because of the increase in the deployment of utility-scale high-voltage PV systems. Rubina Singh, Cordula Schmid and Jacqueline Ashmore of the Fraunhofer Center for Sustainable Energy Systems CSE present an overview of the mechanisms for PID and the impact of degradation, as well as the factors that contribute to its occurrence. They also discuss techniques for the detection, mitigation and predictive testing of PID

PID is a degradation mechanism occurring in high-voltage PV systems because of a large potential relative to ground, and is dependent on the magnitude and polarity of the system. The trend in recent years towards 1000–1500V systems increases the susceptibility of PV modules to PID, as a consequence of the high electric potential. Though degradation caused by high-voltage stress was identified as early as 1978 at JPL [1], PID gained visibility in 2005, when Swanson identified degradation due to polarisation in SunPower modules [2]. The issue, however, has not yet been addressed by qualification standards such as the IEC 61215 and IEC 61646, so a new test method, IEC 62804 TS, is currently being developed.

Cells affected by PID can lose up to 80% power or even more [3]. A power output reduction of over 40% [4] was observed in PV strings of a plant afflicted by PID. This level of power loss adversely affects the operations and financing of PV systems; it is therefore essential to understand and address the issue in its early stages, in order to ensure satisfactory stability and performance of modules over their service life.

PID mechanism

PID is caused by a large electric potential on the module, which in turn results in a leakage current that migrates between the cell and the other components, leading to a reduction in power. As Dr Peter Hacke stated at the 2015 NREL PV Reliability Workshop, leakage current is not a metric for assessing the quality of modules, but a parameter that can be used to detect modules afflicted by PID. Several different mechanisms can lead to PID, but not all of them are fully understood.

> "Cells affected by PID can lose up to 80% power or even more"

The field effect model is one of the most common models used by researchers to explain the cause of shunting, which results in PID [5,6]. Bauer et al. [6] found the migration of sodium ions from the front cover to the solar cell, in combination with certain EVAs and a silicon nitride anti-reflective coating (ARC), to be commonly observed in modules affected by PID. One explanation is that during migration, the charged ions accumulate on the cell surface and result in an electric field, which negates the passivation provided by the ARC, thus increasing surface recombination and reducing the power output. The ions can also diffuse into the silicon, causing inversion of the emitter region and resulting in shunting of the cell [7], as shown in Figure 1. Similarly, PID in some thin-film modules has been associated with the migration of metal ions between the frame and the cell, and significant degradation has been observed in modules using sodium-containing substrates [8].

Experiments have been conducted at Fraunhofer ISE to analyse the effect of the inversion layer on the cell, in conjunction with the development of a theoretical model. The results indicated that there was an inversion of the emitter surface but the emitter was not completely inverted; hence, the model was insufficient for totally explaining PID [9]. Further investigations to fully understand all aspects of mechanisms leading to PID are still ongoing.

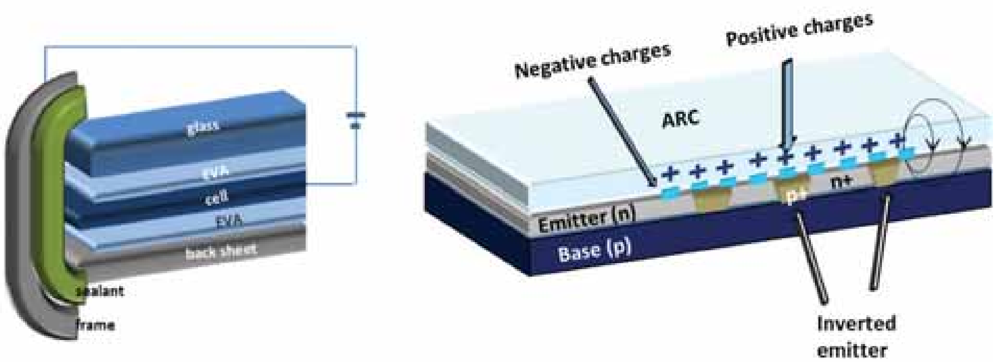

Figure 1. Hypothesised mechanism for PID in crystalline silicon solar cells, based on Bauer et al. [6].

Impact of PID on PV power plants

Numerous cases of yield loss due to PID in PV power plants have been reported in recent years, and this has a detrimental effect on project financing and economics. A survey conducted by PI Berlin [10] reported PID in 20 power plants in Germany; another power plant, comprising 12 strings, showed PID in all the strings, with the majority exhibiting a 10–15% reduction in power output as shown in Fig. 2. In addition, PID affected 41% of the modules in a 10.7MW plant in Spain.

Besides lowering yield, the balance of system (BOS) costs will also be affected. A significant drop in a string voltage will result in a mismatch with the inverter's voltage range, thus increasing inverter losses. Mitigation would require replacement of the affected modules, reconnecting the strings and optimising the inverters to match the string voltages. Such unforeseen mitigation costs would further increase revenue losses [11].

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With the significant decrease in capital cost for solar installations, the focus has shifted to the investments over a PV system's lifetime, making it beneficial to demonstrate a system's reliability to stakeholders. If PID is undetected and unaddressed, the resulting reduction in yield will result in financial losses for investors. The financing of future projects would also become more difficult, since stakeholders would lean towards more reliable technologies [12]. The first step towards prevention or mitigation is to understand the various factors causing PID, and the techniques that can be adopted for timely detection.

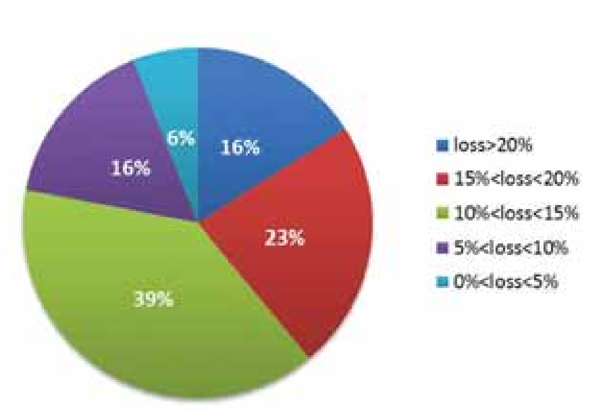

Figure 2. Distribution of power loss at the maximum power point (MPP) for all the strings in a PID-affected PV plant (based on the plot given in Berghold et al. [10]).

Factors contributing to PID

Numerous factors can contribute to PID and can be categorised at the environmental, system, module and cell levels. The occurrence of PID in modules can result from one or a combination of several of these factors, which may be different for different module technologies and climate zones.

Environmental level

High humidity and temperature are the two most significant factors contributing to PID. Various research experiments conducted at, for example, Fraunhofer ISE [13] showed that PID is considerably more likely to occur at high humidity – specifically above 60% relative humidity (RH) – in conjunction with high-temperature conditions.

System level

As mentioned previously, the system voltage with respect to ground and the inverter type significantly influence a system's proneness to PID.

Module level

The module design, glass and backsheet material used can also result in susceptibility to PID. In the past five years several institutes, such as Solon SE and PI Berlin [7], have received a number of modules that were returned because of polarisation; this indicates that recent module designs and technologies may not be immune to PID.

Cell level

The main contributing factors at the cell level are the ARC, base resistivity and emitter sheet resistance [14].

Detection techniques for PID

If left undetected, PID can dramatically reduce a power plant's performance. Some commonly used detection techniques for PID are electroluminescence imaging (EL) and infrared imaging (IR), along with the measurement of I–V curves, which detect any drop in power and operating voltage. Fig. 3 shows EL images for a module, before and after it was tested for PID: the dark regions indicate that the module has degraded as a result of testing. Light and dark I–V can be used for detecting PID, since the cells that are affected will have lower module efficiencies and operating voltages; moreover, those that are severely affected will exhibit reduced open-circuit voltages because of shunting [15].

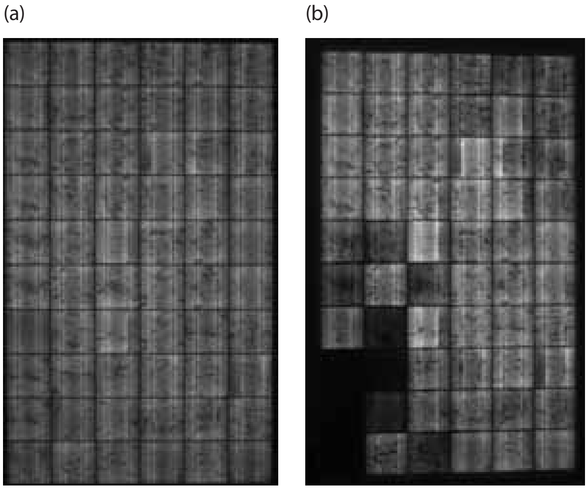

Figure 3. EL images of a module before (a) and after (b) PID testing [16]. Source: Fraunhofer CSE.

Conventionally, the modules would be removed from the field and taken to a lab to conduct EL imaging and I–V curve measurements, but these procedures can now be implemented in the field without uninstalling the modules. EL can be performed on site using a CCD camera while applying a voltage bias to the module at night. IR imaging uses an IR camera while the modules are operating in the field, but might not be an accurate detection method, since PID is not the sole cause of higher temperatures in cells [15]. I–V curve tracers that can be used in the field are also available, but the process of testing each and every module can be time-consuming and expensive. Nevertheless, early detection can help in using appropriate mitigation techniques and prevent further performance and revenue losses over a system's lifetime.

Figure 4. Fraunhofer CSE researcher setting up a module in the environmental chamber for PID testing.

Source: Fraunhofer CSE.

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22%	On snowfield, water surface and white painted rooftop, the additional reverse side conversion efficiency can reach up to 22%	0%	Light Induced Degradation

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Organisation	PID test [26]
Chemitox	60°C/85%RH/–1000V/96h, module immersed in water
Fraunhofer ISE and CSE	60°C/85%RH/–1000V/(96h) × 3 in environmental chamber
PI Berlin	85°C/ 85%RH/ –1000V/ 48h
TUV Rheinland	25°C/-1000V/168h, aluminium foil method
TUV Sud / IEC 62804	60°C/85%RH/–1000V/96h in environmental chamber

Table 1. PID test protocols typically used by different organisations.

PID mitigation

Conditions of high temperature and humidity occur sporadically in the field, giving the modules time to recover from PID. Besides relying on such favourable environmental conditions, various solutions for mitigating and preventing PID are under development at the system, module and cell levels.

In systems using conventional inverters, grounding the negative pole of the system can help prevent PID. Companies such as SMA have developed the PV offset box [17], which reverses the effect of PID in systems using transformerless inverters. If a voltage of the opposite polarity to that of the system is applied, which can be done by connecting an offset box in parallel to the inverter, the modules will almost completely recover from PID. Furthermore, PID can also be mitigated at the module level by using PID-resistant encapsulants, such as Enlight polyolefin encapsulant film [18], ionomer films and chemically strengthened glass.

Various module manufacturers claim to have developed PID-free modules, which are based on the use of PID-resistant components, anti-PID cells and encapsulant technology. Moreover, frameless and glass–glass modules are also considered to be PID free, since a path for a large potential to be set up is not created; however, the use of metal clips for mounting such modules might negate the anti-PID property. Due diligence is therefore required in order to ensure that the bill of materials and associated processes are all PID free, so that PID can be avoided in a system as a whole [19]. In some cases PID might be irreversible if it is not detected in time or if it is caused by electrochemical reactions. To limit future detection and mitigation costs, it is therefore advisable to test modules for PID resistance, where possible, before field installation.

Predictive tests for susceptibility to PID

The two main testing methods employed in the lab simulate conditions for PID using an environmental chamber and the aluminium foil method. Initially, the test was adapted from the damp-heat test specified in the IEC 61215 standard, with environmental conditions of 85°C and 85% RH. Some organisations are currently using a modified test protocol based on the draft IEC 62804 TS test method.

Tests were conducted over a period of 96 hours in an environmental chamber at 60±2°C and 85±3% RH and with a voltage bias of –1000V or the nameplate-rated system voltage; this standard is based on the findings of round robin tests coordinated by NREL [20]. Hacke et al. [21] have reported corrosion and losses in series resistance caused by a combination of very high RH and temperature of 85°C, which does not simulate PID in the field accurately. Moreover, though a humidity of 100% would be preferable, this setting might also induce stress because of condensation in the environmental chamber, which would otherwise not occur in the field [22]. Testing conditions of 60°C and 85%RH were therefore chosen as the most representative.

In 2014 the aluminium foil test method was added to IEC 62804 TS as a simple and inexpensive alternative to the environmental chamber test [23]. The method consists of covering the module surface with a conductive foil and applying the system rated voltage at conditions of 25°C and less than 60% RH for 168 hours [23]. Experiments conducted at Fraunhofer CSE to compare the different testing methods showed that, compared with the aluminium foil method, the use of an environmental chamber results in more uniformity, control and reproducibility [24]. Fraunhofer CSE therefore conducts PID tests based on the IEC 62804 environmental chamber method, as shown in Fig. 4, and has already tested various modules as part of the PV Durability Initiative (PVDI) [25]. The results from the first round of PVDI revealed that susceptibility to PID for most of the modules was detected within the first 50 hours, which supports the IEC's decision to test for 96 hours. However, in order to increase the severity of the test and detect any late onset of PID in the modules, the testing was continued beyond the 96 hours and repeated twice more with interim characterisations. More rigorous testing will ensure that the modules will work reliably over their lifetime.

Some organisations offering PID testing are NREL, Fraunhofer ISE & CSE, Intertek, TUV Rheinland, PI Berlin and PV Evolution Labs; test protocols typically used are given in Table 1.

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Future work

Since PID was discovered relatively recently, there is a need for additional reliable and comparable field data in order to better understand the mechanisms and establish more dependable ways to avoid the phenomenon. Canadian Solar [27], REC [28] and SunPower [29] are some of the manufacturers developing PID-free modules, which have been confirmed by independent testing agencies. Although testing the modules indicates their resistance to PID, this cannot be regulated until an international standard and industry-accepted definition of 'PID-free' are developed. Further research is also required to better understand the PID mechanism, since it has been postulated that emitter inversion causes shunting, resulting in PID; experimental results from Fraunhofer ISE, however, have shown the inversion model to be inadequate in explaining PID. Moreover, though the occurrence of PID has been observed in conjunction with the presence of Na^{+} ions, their actual role in causing PID is not fully understood.

The time it takes for modules to exhibit PID susceptibility is not totally understood either, since modules in different PV plants have manifested PID at different times. Further research and testing are necessary in order to determine acceleration factors which can correlate the module's time to PID onset in the field with lab tests; some organisations are conducting research in this area [30,31]. There is a need for a standard method to accurately determine acceleration factors that can be adapted to different locations and technologies.

In conclusion, the industry has been proactive in identifying and tackling PID, with extensive research under way to understand various aspects of the phenomenon at the system, module and cell levels. Consequently, the factors causing PID are now being identified, leading to the drafting of a test method for standardising PID testing, and to the development of various mitigation techniques. Additional research, however, is still essential, so that further understanding of the phenomenon can be gained, and to prevent this challenge from being an obstacle in the PV industry's remarkable growth.

Authors

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