Potential Induced Degradation
Causes, Effects and Possible Solutions

Abstract

Potential Induced Degradation (PID) is a process that occurs in photovoltaic (PV) cells when the system has a negative potential relative to the ground. As a result, the PV module's efficiency decreases over time. Although PID is a relatively new concept and is not widely understood, techniques already exist to minimise its undesirable effects. The prevention of these adverse effects mainly involves changes in the material used and the system design. However, for systems already affected by PID or for those susceptible to it, a device has been developed that reverses the polarity of the array, forcing the negative charge out of the module.

This report provides background information on PID, including how this degradation process develops, the conditions that make PV systems prone to it, its effects and the methods to correct or prevent it.

Introduction

In the past 5 years, the global solar photovoltaic (PV) capacity has grown at the average rate of over 50% per year. In other words, more and more PV systems have been installed, and at an increasing rate. In addition, as module and associated costs have decreased, PV systems and solar farms have become larger. Over this period, a considerable number of reports amongst the solar community have emerged about unexplained power losses. Eventually, the cause of these was identified as Potential Induced Degradation (PID) (see box on the right). The explanation is simple: for these large installations, a large number of solar modules are required. Once the modules are connected in series, the systems operate at a high voltage. These are the conditions in which PID can occur.

It is now realised that the environment, module material and system design are also related to the degradation process. To understand how each of these factors affects the cells, it is important to understand how the phenomenon develops.

The PID phenomenon

When a PV system operates at high voltage, i.e. >1,000 V, a considerable potential difference is established between the solar cell and the frame. This means that an electrical difference builds up between the system and ground, as the frame is earthed for safety reasons. If the potential is negative (that is, the cell has more electrons relative to the ground), it creates a current that flows from the module frame to the PV cells, known as a leakage current.

> In 2005, Swanson *et al.* summarised data on the inexplicable power losses observed in large systems in an article for the European Photovoltaic Solar Energy Conference. In this article, the cause of these losses was identified as PID, thus highlighting the issue and raising concerns of those in the solar industry. To increase the lifetime and reliability of the solar cells, manufacturers started to invest in solutions to PID. Although many manufacturers claim to have overcome the problem, few PV modules are actually free of PID.

There are three main paths that the leakage currents can take (Figure 1):

1. From the front side of the frame to the cell, through the solar glass.
2. From the side of the frame to the cell, through the encapsulating material.
3. From the back side of the frame to the cell, through the back sheet and the encapsulating material.

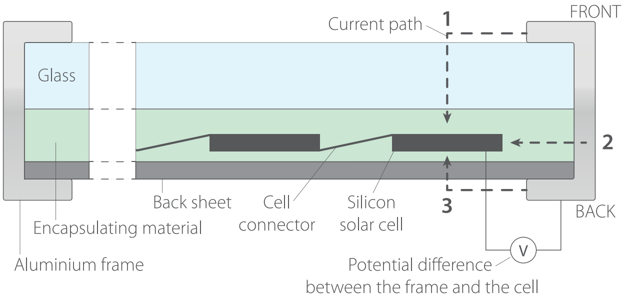

Figure 1: *Paths for leakage currents.*

As relates to the PID effect, the critical current is the one moving from the frame to the cell through the solar glass.

This current allows positive sodium ions from the glass to drift towards the top layer of the PV cells (Figure 2), while negatively charged electrons move away from it via several paths (Figure 3).

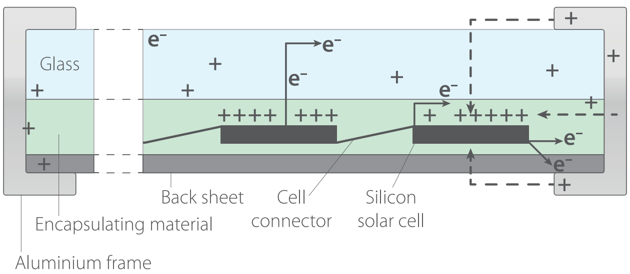

Figure 2: *Positive charge paths towards, and electron escape paths away from, the solar cells.*

The mechanisms that follow after the positive sodium ions reach the PV cell are not yet well known. For now, we know that these positive charges accumulate on the top of the PV cell and interact with the p–n junction, causing a local short circuit (Figure 3).

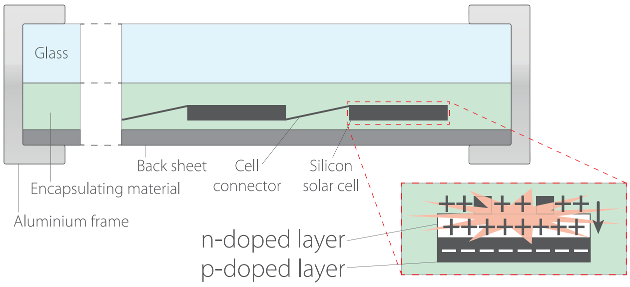

Figure 3: *Local short circuit in the p–n junction after the accumulation of sodium ions on the top of the cell.*

One well-accepted theory about the local short circuit proposes that the sodium ions diffuse into the bulk of the PV cell and act like donor atoms, increasing the concentration of sodium ions in the n-doped layer. Eventually, the ions neutralize the negative doping, reducing the photovoltaic effect of the cell. The sodium ions act as impurities in the cell and become sites of recombination, reducing the amount of current that can be extracted and the potential across the cell, thus lowering performance. More studies are required to confirm whether this is the true degradation mechanism.

If the local short circuit occurred within only a single p–n junction, it would not be a problem. However, it happens in multiple p–n junctions. This reduces the maximum power point and the open circuit voltage, which in turn reduces the total string voltage. As a consequence, the inverter switches on later in the morning than it should because the solar array needs more radiation to reach the inverter's minimum voltage. The inverter also switches off earlier in the evening, as the system voltage drops rapidly with the day's decreasing irradiance.

PID also affects the output current because as the leakage currents between the cells and the frame become greater the output current reduces, which results in a bigger output loss.

> ***"positive charges accumulate on the top of the PV cell and interact with the p–n junction, causing a local short circuit"***

Once PID has affected the array, the modules become increasingly less effective and a loss of up to 70% can be measured (Figure 4).

This graph represents the standard deterioration of a test system affected by PID. However, it is important to note that each PV system performs differently depending on the circumstances that it is exposed to and the materials used in its construction.

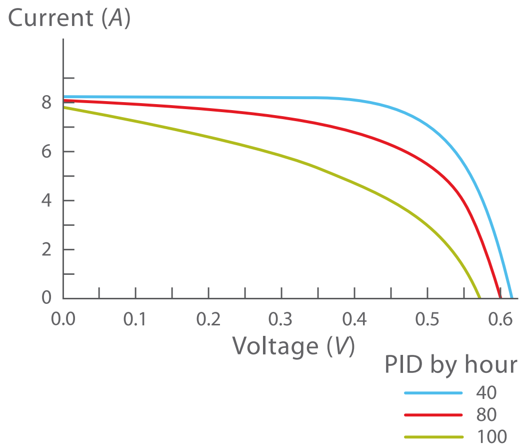

Figure 4: *IV curves of a PV test system affected by induced PID.*

The effect of PID on the IV curve is similar to that of reducing shunt resistance in a solar cell: meaning that any current generated in the cell is lost due to recombination rather than collection at the surface contacts.

Contributing conditions and methods to prevent PID

PID is caused by leakage currents created by the potential difference between the ground and the PV cells. Any factor that increases these leakage currents or the electrical potential (even indirectly) contributes to PID. This therefore also deserves attention.

Contributing factors can be broken down into the three following areas: environmental, material and system design. Is important to note that these factors affect every installation and are considered to have the greatest impact on PID.

Environmental factors

The two principal environmental characteristics that affect how much leakage current will flow through the module are humidity and temperature.

As the PV system is exposed to higher levels of relative humidity, water vapour penetrates the system and makes it more conductive. The sodium ions can move more easily inside the material, and more positive charge is accumulated on the top of the solar cell. As a consequence, leakage current intensifies and PID increases (Figure 5).

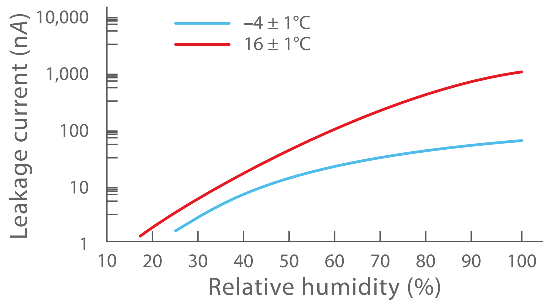

Figure 5: *Relationship between panel leakage current and humidity at different temperatures.*

Increased temperature has the same effect. Higher temperatures can cause the leaking of sodium ions in the system and also accelerate their mobility; this results in increased current intensity. When the leakage currents become more intense, the current that generates power is weakened.

Although temperature and humidity have a strong influence on PID, they are hard to control. Therefore, the techniques and methods to prevent PID focus on other areas.

Material factors

A PV system is composed of many different elements. The qualities and properties of each one can determine how prone the cell is to PID. The main components of a module that influence degradation are the anti-reflective coating, the glass and the encapsulating material.

Anti-reflective coating: The anti-reflective coating helps to increase the amount of light captured by the solar cell, which results in higher currents. However, depending on its thickness, refractive index and coating homogeneity, the anti-reflective coating affects PID in different ways. For example, the widely used anti-reflective coating silicon nitride (SiN) can accelerate the PID process when its layers accumulate highly mobile sodium ions (Figure 6).

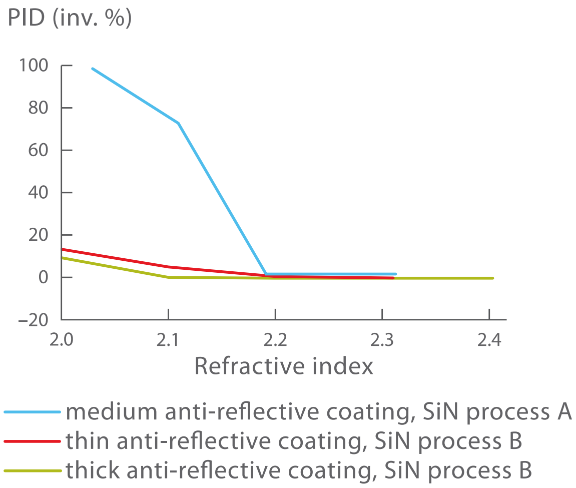

Figure 6: *PID measured in three SiN anti-reflective coatings with different thicknesses, refractive indexes and homogeneities (directly related to the process through which SiN is made).*

Solar glass: Researchers have shown that some types of glass are more susceptible to increased leakage currents than others. This is because certain glasses have high concentrations of sodium that can be released when the glass is exposed to moisture or high temperatures. Using a type of glass with less sodium (for example, quartz instead of soda-lime) can potentially reduce the PID susceptibility.

Encapsulating material: Because humidity increases the conductivity of the PV system, how permeable the encapsulating material is also plays a crucial part in PID susceptibility. Figure 7 compares the leakage currents of two different types of encapsulating material, 'X' and 'Y', that were exposed to temperatures from –20°C to +48°C. The properties of material Y make the module more impermeable

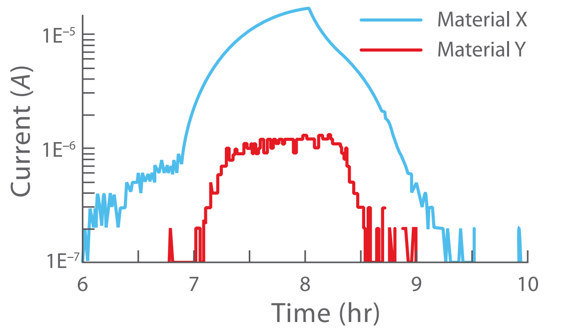

Figure 7: *Leakage currents for two panels with different types of encapsulating material (T_{MAX} = 48°C; RH = 50%).*

than those of material X; therefore, a system using material Y will have decreased leakage current and will be less prone to PID than one using material X.

System design factors

PID occurs when the system has a negative potential relative to the ground. A simple solution is to ground the negative pole of the array and make the system operate only in a positive potential, a process known as functional earthing. Excluding the case where the cell suffers electro-corrosion, this method works well. However, in the past few years, transformerless or non-isolated inverter technologies have been widely adopted, and these do not allow for functional earthing of the array.

Another possible solution is to install a PV-offset box. During the night, this device applies a positive potential to the system, discharging any particles and reversing the polarization effect (Figure 8).

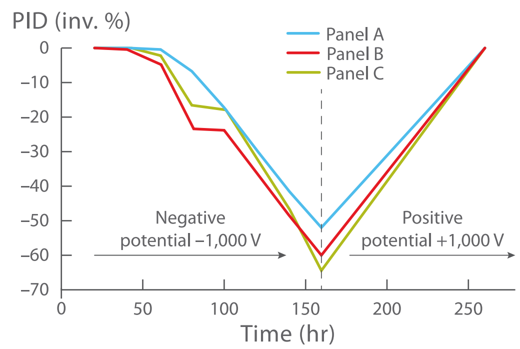

Figure 8: *Correction of PID is possible if the voltage that goes through the system is reversed.*

Summary

PID is a degradation process observed when a PV system is exposed to a high negative voltage relative to ground. The temperature and humidity to which the solar system is exposed enhance this effect.

The PID problem described occurs when a negative voltage relative to the ground creates a current that flows from the frame towards the solar cell. This current accumulates sodium ions in the top of the cell. These ions interact with the p–n junction and build up to the point where they cause a local short circuit. This decreases the ability of the cell to collect minority carriers, and therefore decreases the output power.

There are several proposed methods to prevent the occurrence of PID. As the weather cannot be changed, and having a system operating at a low voltage is impractical, the solutions focus on impeding the leakage current by changing the material or the system design.

Three factors related to material selection can greatly affect PID: the anti-reflective coating, the encapsulating material and the solar glass. As regards the system design, the most significant factor is how the system is grounded (if at all). Grounding the negative leg of the PV system can prevent the occurrence of PID, as the array will always be at a positive potential compared with the ground. However, not every system can be grounded in this way, depending on inverter technology used. For systems that cannot be functionally grounded, it is possible to use a device that changes the bias of the array during the night, releasing any negative charges.

It is important to note that PID occurs mainly on crystalline silicon modules. This type of module is widely used, and many systems and solar farms were installed in the past without any PID testing or preventative measures. Degradation of these systems could represent a significant problem in the near future.

> *"PID occurs mainly on crystalline silicon modules … Degradation of these systems could represent a significant problem in the near future."*

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