Impact Of Environmental Hazards On Internal Soiling Within Concentrator Photovoltaic (CPV) Modules

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Abstract: Environmental conditions have a significant impact on internal soiling of a CPV system, which affects overall system performance and efficiency. The International Electrotechnical Commission (IEC) 62108, Section 10, standard includes accelerated testing such as temperature cycling, damp heat, and humidity freeze to assess a CPV module's ability to withstand environmental hazards that can compromise the typical 25-year lifetime. This paper discusses the IEC 60529 ingress protection (IP) test protocols and how they can be used to evaluate the performance of CPV modules to block water and particulate contaminants. Studies with GORE® Protective Vents installed in a CPV module and subjected to environmental hazard testing have shown increased reliability of the module over the lifetime of the system by protecting the seals from pressure differentials and keeping out contaminants.

Keywords: Venting, Pressure, Pressure Equalization, Particulation Protection, Dirt, Temperature Cycling, Ingress Protection, Internal Soiling, Water Protection, IP Standards, IEC 62108, IEC 60529, Reliability, Environmental Contaminants
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INTRODUCTION

The solar industry is changing rapidly as new technologies are developed and cell efficiency improves. Maintaining a clear lens and minimizing lens deflection are essential for ensuring high efficiency of CPV modules. As the cell technology becomes more sophisticated, electronics become more complex — making it more critical to prevent internal soiling. The International Electrotechnical Commission (IEC) 62108, Section 10, defines testing protocols that can be used to assess the ability of a CPV module to withstand environmental hazards such as temperature cycling, damp heat, humidity freeze, and in some cases, the impact of hail.

While these tests provide excellent information about the durability of the CPV module, they often do not simulate the real-world conditions to which the module is exposed. For example, a CPV module that is installed in a desert can encounter high winds and extensive dust exposure — all while experiencing the pressure differentials caused by rapid temperature changes as a storm approaches. These types of environmental changes have led the industry to incorporate ventilation into the modules. Ventilation allows air to flow into and out of the module to equalize pressure; however, the vent must also protect against water and particulate contamination.

An internationally recognized test method for measuring the potential of liquid and contaminant ingress into a sealed enclosure is the IEC 60529 standard. This testing can increase customer confidence that the modules are designed to prevent contaminant ingress throughout their 25-year life expectancy. Having collaborated with manufacturers of solar equipment for more than a decade, W. L. Gore & Associates uses the IEC 60529 ingress protection (IP) test protocols to evaluate the ability of sealed enclosures, such as CPV modules, to protect against water and particulate ingress.

IEC 60529 INGRESS PROTECTION TEST METHODS

IEC 60529 ingress testing protocols can be used to evaluate the ability of CPV systems to withstand harsh environmental conditions. The standard specifies the protection an enclosure provides against entry of solid objects and water. IP ratings consist of two numbers (IPXY), with X indicating protection against solid objects and Y indicating the level of water protection.

Solid Object Protection

The IP testing for solid object protection is based on the size of particulates that can enter an enclosure (Table 1). These tests are linear in that if an enclosure meets IP6Y, it can be assumed that the enclosure also meets IP1Y through IP5Y.

CPV modules are exposed to particulates that vary in size and shape, ranging from large masses of dirt to grains of sand or microscopic pieces of dust. Therefore, IP5Y or IP6Y best simulate real-world conditions of

TABLE 1. Level of Solid Object Protection

X	Protection Level
0	No protection
1	Solid foreign objects ≥ 50 mm in diameter
2	Solid foreign objects ≥ 12.5 mm in diameter
3	Solid foreign objects ≥ 2.5 mm in diameter
4	Solid foreign objects ≥ 1.0 mm in diameter
5	Dust entry limited so operation of apparatus or safety is not compromised
6	No dust particulates enter

the environments where CPV modules are frequently installed. With IP5Y, the manufacturer must specify the amount of dust (i.e., number of grams per area) that will interfere with the module's correct operation. This entails extensive testing to prove that the amount the manufacturer specified will not compromise the CPV performance over its 25 years of expected life.

Gore recommends testing for IP6Y because the pass/fail requirement is clearly defined and the results indicate a more robust design — a housing that completely blocks ingress of all particulates. Based on extensive testing, GORE® Protective Vents have proven that they meet IP6Y and ensure that contaminants do not enter through the vent. Also by equalizing pressure, these vents reduce stress on the housing seals, thereby mitigating potential leak paths.

Water Protection

The IP testing for water protection identifies whether water can enter the enclosure based on the amount and pressure of water exposure (Table 2). These tests can be divided into two types: water spray and full immersion. Unlike the foreign object testing, the water protection tests are not linear. For example, an enclosure with an IPX7 rating protects against immersion in one meter of water for 30 minutes, but it does not address wind-driven, high-pressure spray as defined by IPX6.

Because CPV modules are installed all over the world, they can be exposed to a broad range of precipitation — anything from light showers to torrential rain — but they rarely encounter situations in which they are immersed under water. The IP water protection protocols that best address these types of environments are IPX4, IPX5 and IPX6.

The IPX4 test assesses spray protection similar to an overhead shower. For ten minutes, a showerhead sprays water toward the enclosure from a distance of 300 to 500 millimeters (mm) while oscillating through an angle of almost 360° (i.e., 180° on either side of vertical).

IPX5 and IPX6 both test water exposure using pressure jets. IPX5 simulates a regular rainstorm, while IPX6 represents a driving thunderstorm or a high-

TABLE 2. Level of Water Protection

Y	Protection Level
0	No protection
1	Drops falling vertically
2	Spray at angle up to 15° on either side of vertical
3	Spray at angle up to 60° on either side of vertical
4	Splash from any direction
5	Low-pressure jets from any direction
6	High-pressure jets from any direction
7	Temporary immersion: 1 meter for 30 minutes
8	Continuous immersion under conditions agreed upon between buyer and seller
9k	Steam directed at high pressure from any direction

pressure cleaning system. Water is sprayed from the nozzle at a distance of 2.5 to 3.0 meters from the enclosure, with variations in nozzle diameter, spray rate, and spray diameter depending on the specific test (Table 3). These tests should last at least three minutes, with each square meter of surface area being sprayed for at least one minute.

TABLE 3. Water-Spray Test Specifications

Test Specification	IPX5	IPX6
Nozzle diameter	6.3 mm	12.5 mm
Spray rate	12.5 L/min	100 L/min
Spray diameter at 2.5M from nozzle	40 mm	120 mm

The environments in which CPV modules are installed can experience dust or rain storms, with desert wind speeds of at least 40 kilometers per hour or tropical storm winds ranging from 60 to 240 kilometers per hour. In addition, during routine maintenance, high-pressure washers are typically used to clean the outside of the panels. Because CPV modules are exposed to these extreme conditions for 25 years or more, Gore recommends testing to IPX5 or IPX6. GORE® Protective Vents consistently meet or exceed IPX6 ingress protection.

IP TESTING OF CPV MODULES

Gore performed IP solid object testing to demonstrate the impact of pressure differentials on two CX-M400 CPV modules supplied by the leading manufacturer, Soitec. These CPV modules have a rugged design that includes a durable GORE® Snap-In Vent to equalize pressure while providing a barrier against liquids and contaminants (Figure 1).

Gore did not want to physically tamper with Soitec's CPV modules, so for the purpose of this testing, the engineers damaged the vent in one module by removing the cap and creating a cut in the membrane eight millimeters in length — damage that does not occur in real-world conditions (Figure 2).

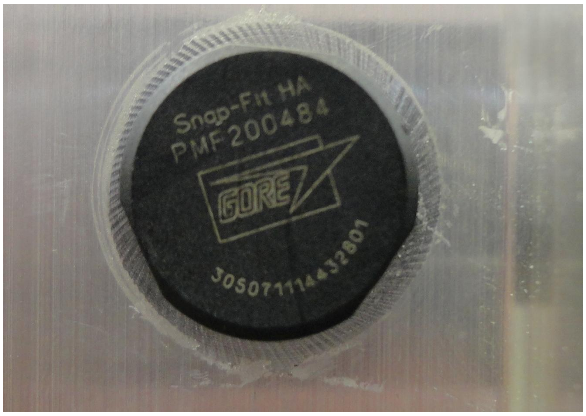

FIGURE 1. GORE® Snap-In Vent.

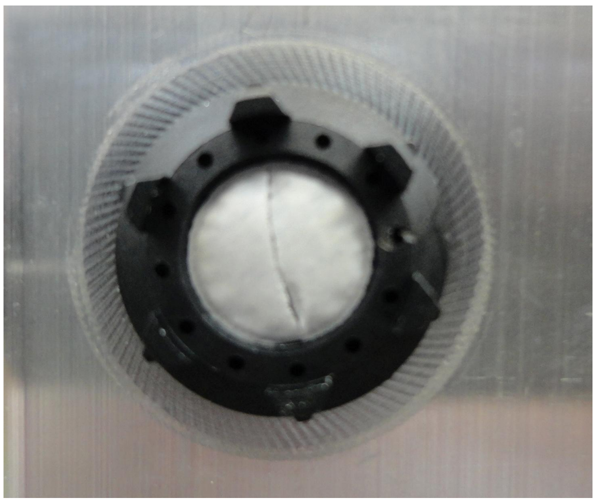

FIGURE 2. Intentionally Damaged Vent.

Test Method

To perform the IEC 60529 solid object test, Gore followed the procedure for Category 1 enclosures, which are defined as those in which internal air pressure deceases below that of the surrounding air during normal operation. The laboratory conditions were maintained at a temperature of 25 ± 2°C with a relative humidity of 55 ± 2 percent.

The standard calls for talcum powder with a particle size range of 7.2 to 9.2 microns. Gore's team used dust particles more representative of real-world conditions of 1 to 100 microns in size. The dust contains 90-percent Arizona test dust and 10-percent salt. The modules were installed in a test chamber with a volume of 3.5 cubic meters (Figure 3), and the test was performed as follows:

1. A vacuum pump reduced the internal pressure of the CPV modules by creating a depression equaling 20 mbar (2 kPa) in accordance with the standard to draw dust into the enclosure.
2. Air containing the dust particles was drawn into the chamber vertically at a rate of 1600 cubic meters per hour, equaling a wind speed of 30 kilometers per hour.
3. The test was continued for 45 minutes once internal conditions were stabilized.

FIGURE 3. Test Chamber With Two of Soitec's Concentrix™ CX-M400 Modules.

Test Results

The CPV modules were removed from the chamber and visually inspected for dust ingress. On the exterior, both vents were covered with dust, indicating that they were exposed to a substantial amount during the testing (Figure 4).

FIGURE 4. Outside of Module After Test.

Inside the modules, the unaltered vent remained clean, and the module was free of dust (Figure 5). However, the damaged vent allowed significant amounts of dust to enter the module (Figure 6).

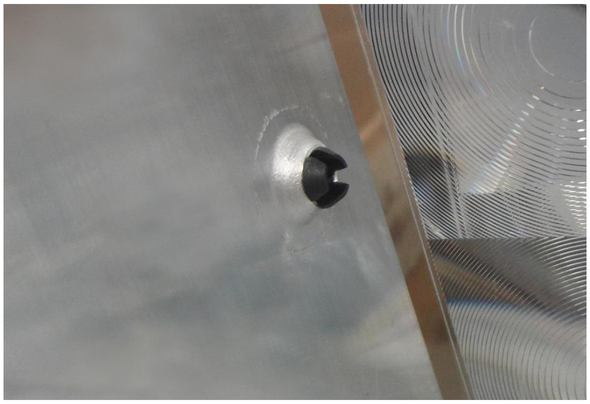

FIGURE 5. Inside of Module With GORE® Snap-In Vent.

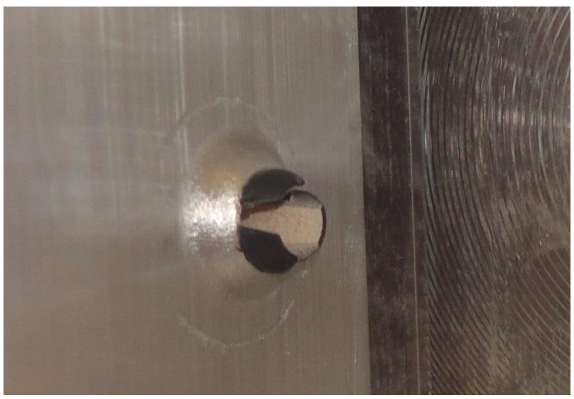

FIGURE 6. Inside of Module With Damaged Vent.

Inside the module with the damaged vent, the dust accumulated in the corners and edges near the silicone due to static electricity of the aluminum (Figure 7). This makes having dust protection even more important, because the dust will most likely stay positioned on the lens, reducing efficiency.

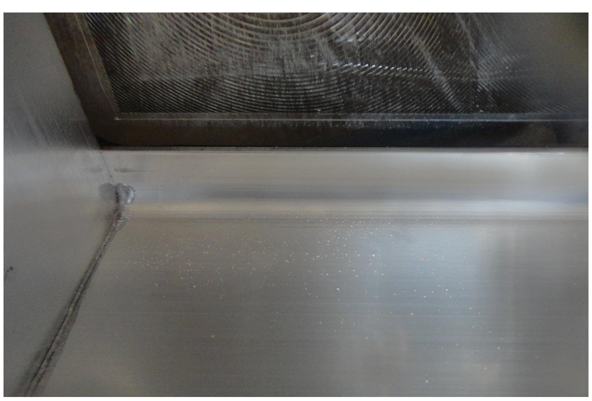

FIGURE 7. Dust Collected on Lens.

CONCLUSION

Because the life expectancy of CPV modules is at least 25 years, it is important to evaluate the module's ability to prevent ingress of contaminants after exposure to environmental hazards. Performing IEC 60529 ingress protection testing after completing IEC 62108, Section 10 testing improves the evaluation of the CPV module's durability because the test results reflect more realistic real-world conditions. This testing sequence clearly evaluates a module's ability to withstand contaminants after it has been exposed to environmental hazards, such as rapid temperature changes, damp heat and humidity freeze.

The results of the testing presented in this paper demonstrate that Soitec's Concentrix™ Technology CX-M400 CPV module has a very robust design that maintained reliable performance in challenging conditions. The GORE® Protective Vent helped prevent any dust ingress, enabling the CPV module to pass IP6Y testing. Also by equalizing pressure, these vents reduce stress on the housing seals, thereby mitigating potential leak paths. Although other options such as metal mesh products can equalize pressure, they will be challenged to pass the IEC 60529 IP5Y or IP6Y standards.

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