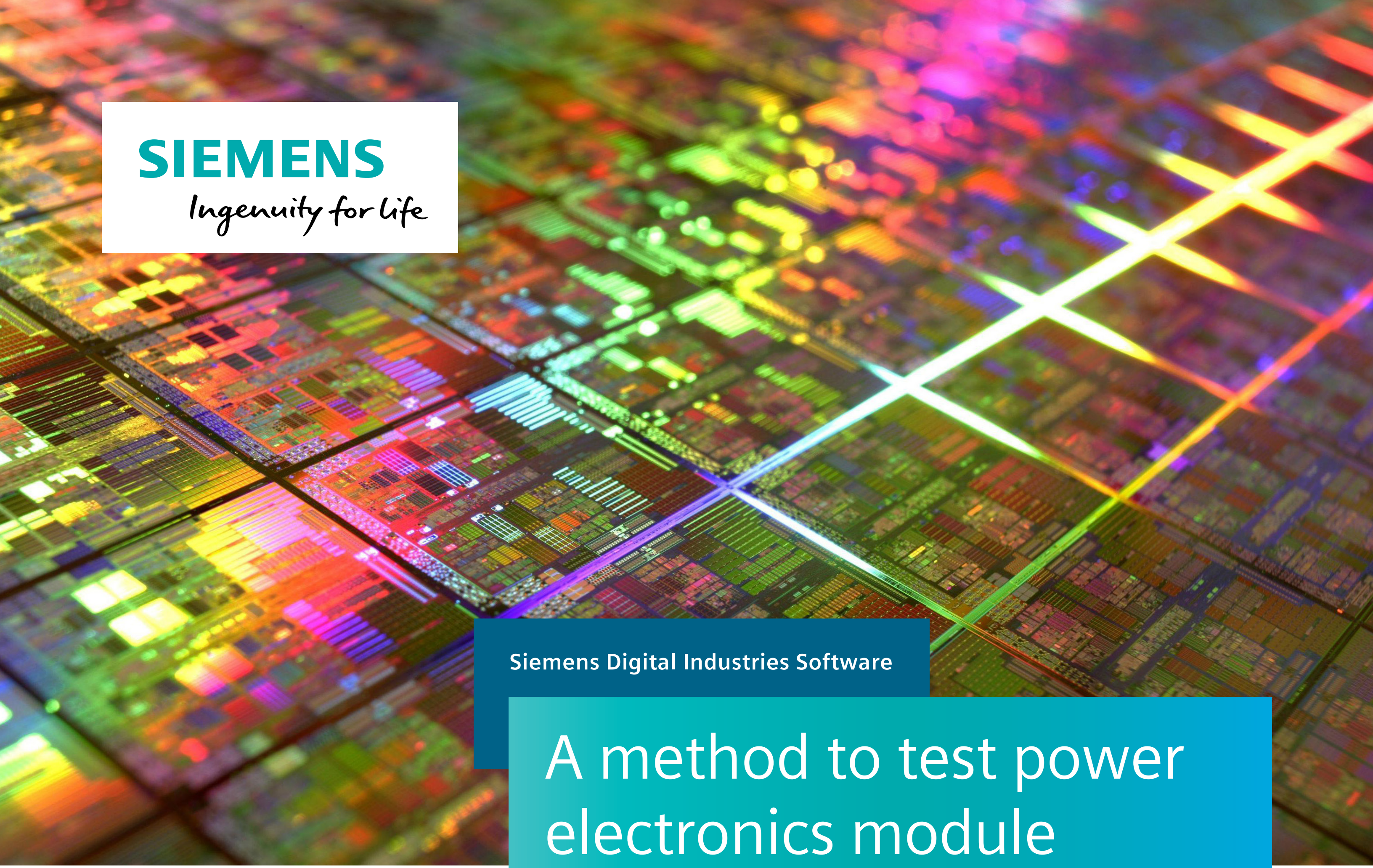

Siemens Digital Industries Software

A method to test power electronics module lifetime

Mechanical analysis

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Introduction

A new method for characteristic measurement and reliability testing of thermally sensitive power electronics modules is more efficient and gets to the problem quicker.

With the focus on energy savings, there is a rapidly increasing emphasis on power electronics modules used in reusable energy applications, such as solar arrays and wind turbines, as well as the power grids that deliver electric energy throughout the world. They are used in electric and hybrid vehicles and their charger stations. Motor drive controllers and even consumer product chargers use them. With this much use, small improvements in their efficiency can save huge quantities of energy.

Meanwhile, several industry consortiums around the world are focusing on improvements to today's power electronics modules and their applications. The companies in these consortiums are concerned not only with the efficiency of the power electronics modules, but also their reliability because many of the applications require modules that must last for years and decades without replacement.

The reliability challenge in power electronics

Many of the applications for power electronics modules require long life spans. For example, in wind turbines that may be located out in the oceans, it's impractical to replace the modules. For solar arrays on satellites, it's basically impossible to fix them. Electric vehicles and hybrids are expected to last 15 to 20 years without major repairs. So the challenge is to create modules at low cost and weight that will not only support the extremely high current requirements, but also last for many years. One method is to over-engineer the modules but this approach adds to the cost and weight.

If they are designed to meet requirements without over-engineering, how can they then be tested for expected lifespan reliability without putting them in a test environment for years, even decades? The main issues that typically affect reliability are thermal stresses and overheating. We can approach this problem in steps. The first step is to design the modules so that they will work from a heat conduction point of view. The second step is to provide a method of testing the modules for their expected lifetime.

First step: Designing components and electronic products for good heat management

The biggest enemy of reliability in electronic products is heat. In an integrated circuit, excessive heat at the die can drastically reduce the chip's life. In power electronics modules, such as IGBTs or MOSFETS, the constant heating and cooling caused by power cycling creates thermal stresses. To first design these modules for reliability and then test them for expected lifespan, a combination of design software and test and measurement hardware is needed.

Designing the internal components and the power electronics modules themselves is typically a two-step process. The first challenge is designing the package for optimized flow of the heat generated at the device junction through the multiple heat paths out to the extremities of the package. If optimized, the heat will flow into the printed circuit board (PCB) through conduction, be cooled by fluid (typically air) flowing over a heat sink (convection) or heat pipes, or radiate (radiation) into ambient air.

A virtual prototype of the package can be analyzed with thermal simulation software to optimize the heat flow during the design process. This is done by providing the physical structure of the package and thermal properties of all the various layers and then using computational fluid dynamic (CFD) algorithms to estimate the flow of heat through the structure. Various experiments can then be performed with the virtual prototypes.

Once a physical prototype of the package is built, the exact thermal characteristics can be determined using sophisticated measurement hardware, such as the Simcenter T3STER™ thermal characterization system. This tester measures and graphs the layer-by-layer thermal capacitance and resistance on a graph called a structure function.

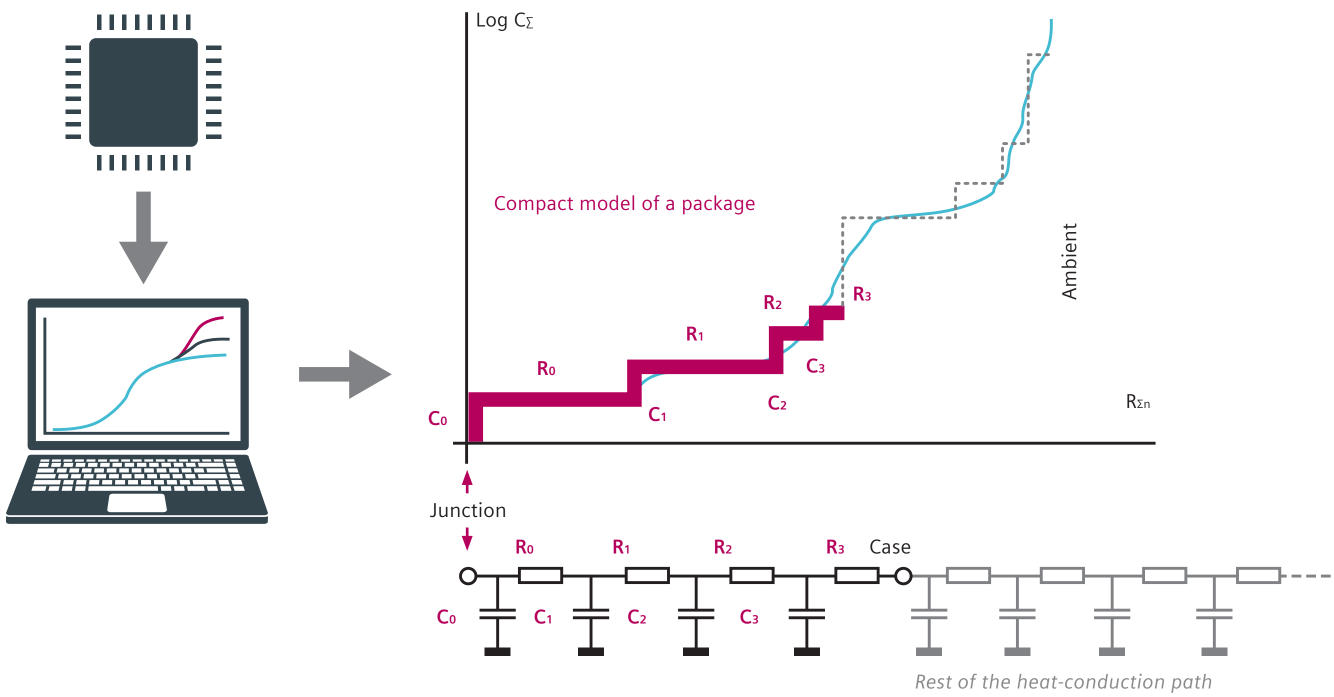


Figure 1 – An IC package structure function, as measured by the Simcenter T3STER hardware, can identify layers of high thermal resistance and capacitance.

Figure 1 shows a structure function that illustrates the heat flow path from the IC junction to ambient. Horizontal sections of the graph line represent layers in the package that have more resistive traits, whereas more vertical line segments represent layers with higher capacitance. By analyzing the graphs, you could determine that, for instance, a certain layer is more highly resistive to the heat flow than desired and needs to be either thinner or made from a more conductive material. A change to the package design and a new prototype for testing would result.

Reliability testing in power electronics

So now you have designed a module with good heat management, that is, it has significant heat flow paths from the junction to ambient. But you still don't really know the expected lifespan. A method of accelerating the lifespan testing and understanding what exactly is going to eventually cause the modules to fail is needed.

The main issue with high power electronic modules is the thermal stresses imposed by the repeated heating and cooling as the module powers on and off during its normal operation. In today's applications, these modules typically run from 100 to 1,500 amps with life expectancy of tens of thousands up to millions of power cycles. These thermal stresses and overheating can cause any number of failures. The various layers of the substrate can separate and, because air is a poorer heat conductor than the solid material, the well-designed heat path will fail and the die will overheat. The same thing can happen if the actual substrate material forms stress cracks. A power electronics module has multiple wire bonds connecting to the die to carry the heavy current loads. These wire bonds can eventually crack because of the thermal stresses or can detach because of solder failure.

Classic versus advanced reliability testing

The classic method of lifespan testing for a power electronics module requires multiple cycles through various stages in a laboratory. Typically, the IGBT module is hooked up to a power cycling source. The module may be cycled through a few hundred or a thousand cycles. Then the module is dismounted from the power cycler and taken to a lab for failure testing. If the module has not failed, the process of power cycling and failure testing is repeated. Once the module is determined to have completely failed, it is taken to a lab to determine the cause of failure. This process can involve X-ray scanning, visual inspection or even destructive dissecting of the module.

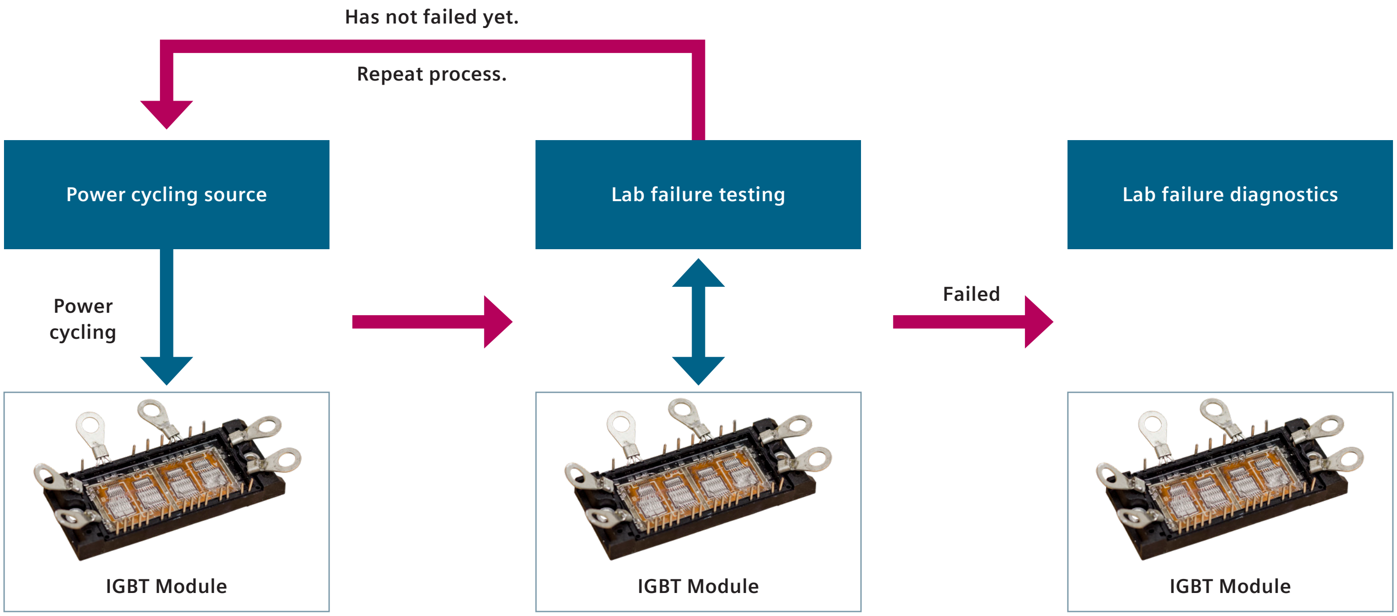


Figure 2 – The classic method of reliability testing is a long process with indeterminate failure cause results.

There are several issues with this classic method of reliability testing. First, it's a long process. The repeated mounting, power cycling, dismounting and failure testing is time-consuming, especially if the number of cycles to failure is high. Second, the cycle count to failure start may be indeterminate. Only after the module has completely failed could it be determined to have failed in the lab. Also, if the diagnosis shows multiple failures, it is not always possible to determine the cause and effect; that is, which failure was the initial one that caused the other failure.

New technology for reliability testing

A more efficient process is needed that can determine the exact cause of the failure quickly. Such a solution needs to be able to measure electrical and thermal effects in the module during the power cycling and recognize the failure cause in real-time, without having to rely on a post-mortem diagnosis. If the power cycling and measurement is contained in the same hardware, there is no need to dismount the modules from the power cycler and take them into the laboratory for failure analysis. Recent developments in the industry, such as the Simcenter POWERTESTER 1500A, are providing this capability.

The key to efficiency is to combine the power cycling with on-line, real-time diagnostic testing and to be able to analyze multiple characteristics of the module under test simultaneously. An example uses a maximum of 1,500 amp power cycling that can either be applied to a single module or as many as three separate modules. It has measurement capability that senses the module's structure, voltages, junction temperature, and other characteristics in real time. The touch-screen controls make it easy to set up and run, making it appropriate for both laboratory and production environment usage.

Using the real-time structure function

The structure function produced by the Simcenter T3STER provides the ability to "look" inside of the module and measure the thermal characteristics of the module's substrate layers. This same technology can be used during the power cycling to sense substrate layer delamination and cracking.

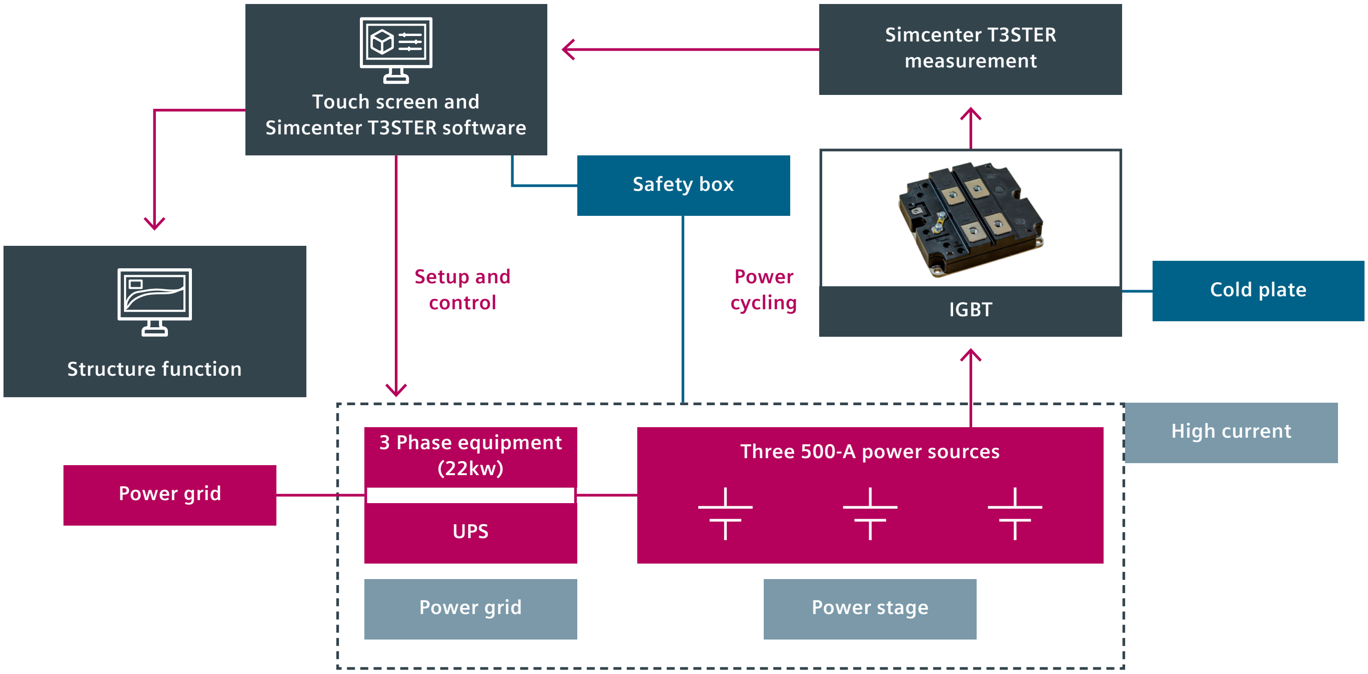


Figure 3 – Combining power cycling with real-time diagnostics solves many of the issues with the classic method of power electronics reliability testing.

Figure 4 shows a structure function graph with snapshots taken at this particular module's 0; 5,000; 10,000; 15,000; 20,000 and 25,000th cycles. The blue and green lines are coincident and basically show the original "good" module's layer characteristics. But at the 20,000th cycle, we see that the lines start to go more horizontal, indicating an increase in the resistance of the base plate solder layer. This continues to happen through the 25,000th cycle. The increase in resistance indicates a delamination of the layer, an interruption of the heat path from the die to ambient, and will probably result in overheating of the die and eventual failure.

With the classic method of testing, a failure may not have been recognized at this point. Later in the classic process, after complete module failure, multiple layers may have delaminated because of the excessive heat, but failure of the initial layer would not have been seen.

Other causes of failure diagnosed

The structure function can be used effectively to sense such failures as substrate layer delamination and cracking. But other failures can occur in the modules, such as wire bond cracking or solder failure. For these types of diagnostics, the power tester has to include very sensitive methods of measuring changes in voltages and currents. For a module that contains multiple wire bonds per die, the ability to see when a single bond has failed is needed. This can be achieved by measuring small increases in the forward voltage being applied during powering up of the module. If a bond fails, the resistance to the die will increase slightly, thus increasing the forward voltage slightly.

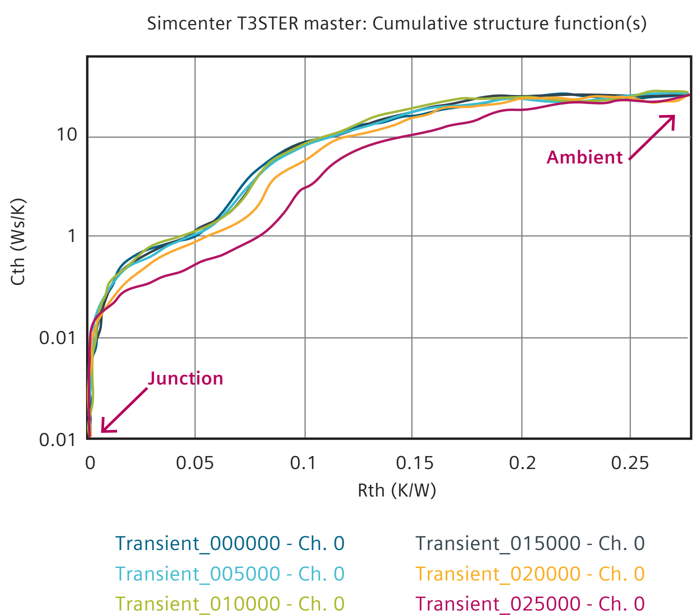


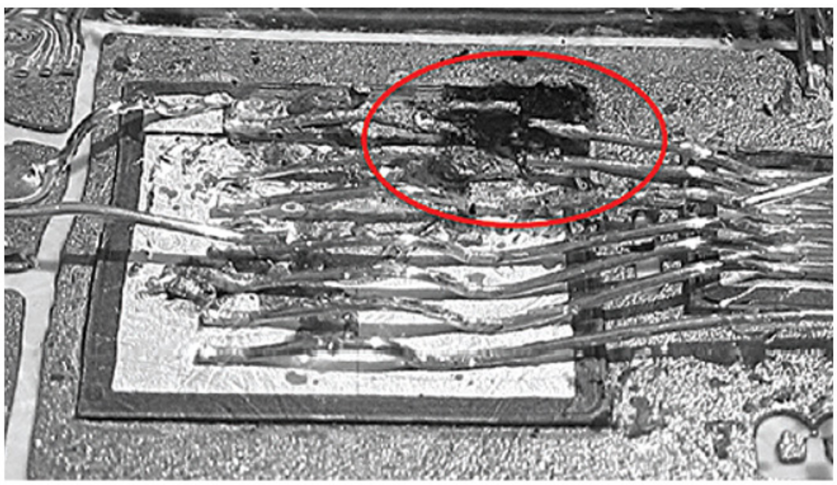
Figure 4 – The structure function can identify module layer failures real-time during power cycling.

Benefitting from the new technology

The most obvious beneficiaries of a power tester like this that can be used in the lab, as well as the manufacturing floor, are the power electronics module suppliers themselves. They have three opportunities to use such a tester. The first is to use it during the design process to determine if they have created a design that meets their reliability goals while achieving their cost and weight specifications. Secondly, they then can use it to generate datasheet reliability specifications for their customers. The third use is as a production-line quality-assurance tester to make sure that their production line has not varied by random sampling of modules as they come off the line.

The second beneficiaries are the Tier 1 suppliers who purchase the modules and then use them in their products. They might want to do their own reliability testing to determine lifespan expectancies, either to double-check the supplier specifications or if the supplier has not supplied specifications. They might also want to do random sampling of modules as they purchase them to make sure they still fall within specifications.

OEM product developers have the most interest in good reliability. If their end-product does not hold up, they may be subject to high warranty costs, recalls and reputation damage. They will surely want to test these modules before incorporating them into critical parts of their products.



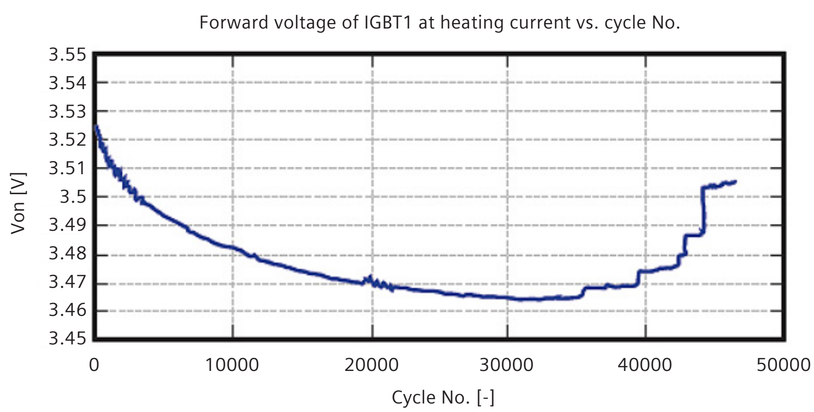


Figure 5 – A detached or degraded bond wire can be sensed by a slight increase in the power forward voltage.

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based on the article "A new way to test power electronics modules"

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