Reliability of Enphase microinverters

Contents

Introduction

The current generation of Enphase microinverters has a mean time between failures (MTBF) of over 600 years for the IQ platform. The concept of MTBF is often confused with a component's expected useful life. This document describes MTBF as it relates to the product's service life, infant mortality failures, wear-out, and the standards and techniques used in estimating these failures.

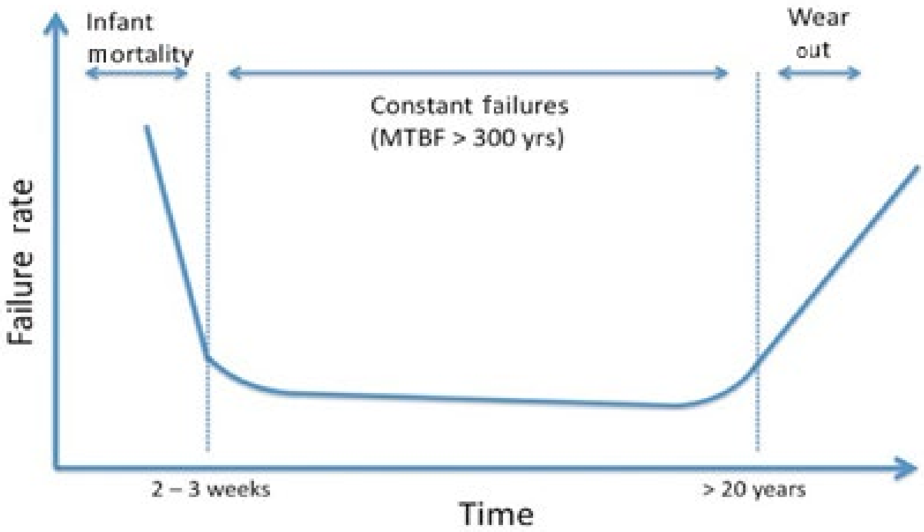
Failure curve

When deployed in large numbers, every product exhibits a characteristic failure rate curve over its service life similar to that shown in the following graph. This is known as the bathtub curve due to its characteristic shape.

The curve can be divided into three different segments according to the types of failures:

- Early failures (known in the industry as infant mortality failures)
- Constant failures
- Wear-out

The Enphase microinverter also exhibits this typical failure curve.



Infant mortality failures

This area of the curve represents the quality of the manufacturing process, and these failures typically manifest themselves very soon after installation. The duration of this period in which infant mortality occurs is ascertained by analyzing field data. In the case of the Enphase microinverter, if infant mortality occurs, it typically occurs within two to three weeks of installation.

To ensure that infant mortality is minimized, every Enphase microinverter undergoes extensive testing during manufacturing, including visual optical inspections, in-circuit tests, functional tests, and system tests. Enphase has developed custom test stations to subject every microinverter to a rigorous manufacturing test standard.

Enphase analyzes each field failure and applies rapid corrective action to an already strictly-controlled manufacturing quality process. In this manner, there is a continuous improvement in infant mortality.

FT-D (manual setup)

FT-D (manual setup)

GT-C and toaster

Wear-out

The wear-out mechanism determines the useful service life of any product. Wear-out causes an increasing failure rate at the end of the useful service life of a product. Therefore, the product's service life is determined by the level of field failures that become objectionable to the user and operator of the product.

Estimating wear-out

The Enphase microinverter is designed for a service life of over 25 years. The curve's wear-out segment represents the longevity of the construction and component choices of the product for the designed operating environment. There are various methods to determine the onset of wear-out of a product.

- The most common method is to observe failure over the duration of interest of previous generations of similar products and use failure data to model the failure mechanisms of the new product.

This is impractical for entirely new products with long service life goals, such as the Enphase microinverter with a service life design goal greater than 25 years.

- The second method is to subject the new design to a theoretical study by evaluating the wear-out of each component based on data provided by component vendors.
- The third and most practical method is to subject the new product to an accelerated lifecycle test (ALT), which simulates the entire service life of the product in an extremely short period.

Enphase uses the ALT method to estimate wear-out. One of the techniques used is to subject the Enphase microinverters to a group of extremely stressful environmental tests as prescribed by the test standard known as IEC61215. This test standard is used by solar module vendors to determine the modules' wear-out period. Two key tests were performed over 110 days, as noted.

During these tests, the microinverters are operated at rated power. The units are subjected to AC/DC power cycling under environmental stress conditions. One warning is that such ALT tests do not simulate the effects of UV rays on the device. The effects of UV on the microinverter are not significant as the product is installed underneath the module, and the wiring used is UV-rated. To estimate their wear-out, all new Enphase designs are subject to these IEC61215 tests.

First test

The first test, a damp heat test, is conducted over 1500 hours (approximately 62 days), where the microinverters are subject to 85°C (185°F) and 85% relative humidity. The microinverters are operated while exposed to this environmental condition, and their performance is monitored in situ during this test.

Second test

The second test, called the thermal cycle test, is conducted over 600 cycles where microinverters are subjected to thermal environment cycles from 85°C (185°F)/85% RH to −40°C (-40°F). The microinverters are operated while exposed to this environmental condition, and their performance is monitored in situ during this test. This test takes approximately 75 days.

Mean time between failures (MTBF)

MTBF is not an indication of the actual service life of a product, but it is an indication of the statistical probability that a unit will fail under specific operating and environmental conditions during the period defined by the MTBF.

The MTBF is related to the failure rate in the constant failure segment part of the bathtub curve between infant mortality and wear-out segments. This segment of the curve represents the design's reliability for the chosen operating environment. The MTBF evaluation for Enphase microinverters was done theoretically under the guidelines of the *Telcordia SR332* standard. This standard is applied to determine MTBF for telecommunications equipment deployed in outdoor environments similar to those in which the Enphase inverter is installed.

As the bathtub curve indicates, if a deployed unit has survived, infant mortality does not guarantee that all units fielded will last until the onset of wear-out. As the curve indicates, there will continue to be a low rate of failures until the onset of wear-out.

These are random statistical failures. The larger the MTBF number, the fewer the failures due to random events. Enphase Energy has minimized these random failures through packaging design, thermal management, and by significantly integrating semiconductor technology into the design of the microinverter.

The concept of MTBF is often confused with a component's expected useful life, but these concepts are not the same. For example, a battery may have a useful life of four hours and an MTBF of 100,000 hours. These figures indicate that in a population of 100,000 batteries, there will be approximately one battery failure every hour during its four-hour lifespan.[1]

[1] High availability fundamentals - Sun Microsystems, Inc

To look at the Enphase microinverter MTBF rating of more than 600 years is to compare it in the context of MTBF ratings for other common devices and solar equipment:

Device	MTBF
Traditional central or string inverter	10 - 15 years
Disk drive in a personal computer	57 years
Enphase microinverter	600 years
Solar panel/module	>600 years
Solid-state memory (used in computers)	800 – 1,000 years

The Enphase microinverter MTBF is similar to solar modules. A respected reliability engineering company that tests reliability for organizations such as Boeing and the U.S. Military determined that the Enphase microinverter MTBF is greater than 300 years.

System availability

Enphase microinverter system eliminates the single point of failure resulting from deploying a central or string inverter. As all the PV modules and associated microinverters are connected in parallel, and each of these pairs acts as an independent energy producer, the failure of a single module or microinverter does not affect the performance of the rest of the modules. While there are more inverters in each installation than a single central or string inverter, the high MTBF of each of the microinverters, combined with the parallel connection, ensures a very high level of system availability. In large commercial systems, it is shown through simulation that system availability of greater than 99.8 percent can be achieved compared to 95 to 97 percent for a central or string inverter.

Enphase microinverters have high MTBF

The distributed architecture of the Enphase microinverter system provides the foundation for various design features that enable high reliability:

Components

Unlike traditional inverters that process many kilowatts of power at very high DC input voltages, Enphase microinverters process low amounts of power at low DC input voltages, thereby reducing component stress. In addition, processing low amounts of power enables a high degree of semiconductor integration, dramatically reducing the number of components. Semiconductor components have extremely high reliability.

Thermal footprint

Enphase microinverters process only a small portion of the power of the entire PV array. The internal temperature rise for a single microinverter is relatively small. This reduction in thermal cycling and passive cooling rather than a cooling fan significantly reduces component stress.

Enclosure rating

The Enphase microinverter is rated to NEMA 6. The test for NEMA 6 is that the unit is submerged under a meter of water and must operate for 24 hours. Traditional inverters are typically rated to NEMA 3R, which allows for the intrusion of dust, external air, water, and possibly insects (that is, pad-mount transformers are NEMA 3R rated). A NEMA 6 rating ensures the device is hermetically sealed from environmental intrusion.

Potting

The Enphase M190 microinverter is a potted design. This means that the internal chamber of the enclosure is filled with an encapsulating compound. This extends the life of the device through improved heat dissipation and component protection.

The important metric is to verify theoretical predictions with field failure rates. Enphase microinverter can transmit its performance data to the Enphase servers. Enphase continuously monitors this performance and uses it to corroborate field failure rates with theoretical predictions.

Conclusion

Considering the negative impact of historically high inverter failure rates on installers and customers in the solar industry, Enphase developed a new microinverter technology that has unparalleled reliability. Enphase considered MTBF as one of the key metrics to predict reliability. Enphase implemented test methodologies used in the telecommunications industry (which has some of the highest availability standards in the world) and invested heavily in developing specialized test equipment to support these extra-rigorous standards.

The result of this fixation on reliability is an inverter technology that exhibits an order of magnitude improvement in MTBF compared to existing inverter technology. This improvement was enabled by the integration of semiconductor technology, by controlling the environmental exposure of the components, and by precisely managing thermal elements. Enphase continues to focus on reliability improvements with each successive generation of inverter to reach an MTBF of 600 years, comparable to PV modules.

Revision history

Revision	Date	Description
TEB-00082-1.0	September 2023	Initial release