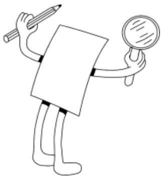

Technical Note

SolarEdge Reliability Methodology

Summary

SolarEdge Technologies develops and sells power electronics for the Photovoltaic market. The heart of the SolarEdge power harvesting system is a unique, patent-pending, distributed solution in which each photovoltaic module is connected to a power optimizer, an energy optimizer which guarantees maximum power to be extracted from each photovoltaic module, and the serially connected power optimizers are attached to a proprietary streamlined inverter which feeds the generated energy into the power grid.

The SolarEdge solution provides many unique benefits, such as increased energy production, improved safety for installer and home-owner, module-level telemetries and troubleshooting, and more. However, in order to achieve these benefits an unparalleled level of reliability must be achieved. PV module manufacturers give 20-25 year warranties on the performance of their PV modules, and in order for the SolarEdge solution to be a viable proposition; it must provide an equivalent warranty and similar level of performance. The SolarEdge power optimizers are designed to function continuously for over 25 years without maintenance in outdoor conditions with extremely low failure rates. The SolarEdge inverter is designed – and warranted – for 12 years of operation. Both products provide industry leading warranties, and the design, analysis, and testing process conducted during their development is industry-leading as well.

The reliability process spans all stages of design and production – from requirements, through design, component testing, production and sub-contractor evaluation, and finally integrative stress testing to prove the overall reliability of the system.

Reliability in Electronics

Reliability is a product's ability to perform under stated conditions for a specified period of time. Reliability concerns the normal functioning of a product over time, as opposed to quality which mainly concerns the normal functioning of a product at the initial stage (at time 0).

Generally, reliability levels are expressed as the probability that a part will fail to function after a specified time interval. The same part will have different probabilities of failure under different use conditions.

In the electronics industry, this failure rate over time exhibits certain characteristics that are commonly referred to as the "Bathtub Curve" (figure 1). Failures have been classified into the three regions of early failures (initial failures), intrinsic failures (random failures) and wear-out failures, according to the time of occurrence:

- Early failures (known also as "infant failures"): These failures occur at a relatively early time after the start of use. The main causes of initial failures are manufacturing or material defects. Failure rate at this phase decreases over time.
- Intrinsic or random failures: These failures occur at a fairly constant rate after the initial failure period until wear-out failures occur. Majority of electronic components fail with constant failure rate during this stage.
- Wear-out failures: These failures are caused by wear and fatigue, and occur due to the physical limits of the materials. Failure rate at this phase increases over time.

It follows that reliability can generally be defined as a function of time (t).

To achieve highly reliable systems, it is important to reduce the initial failure rate, provide a low rate of intrinsic failures, and ensure that wear-out failures start occurring only after the systems' useful lifetime ends.

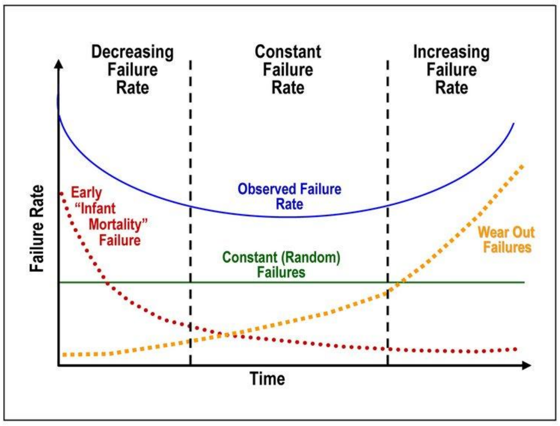

Figure 1 - *Bath Curve*

SolarEdge Reliability approach

SolarEdge Technologies considers obtaining high reliability and quality as a high priority task in the company. The approach we have taken is – to the best of our knowledge – more comprehensive and in-depth than any of the approaches prevalent in the industry today.

Reliability tests require expensive resources and precious time. There are estimation tools to evaluate the life time of a system. However, the available tools are notorious for neglecting various failure mechanisms and stresses. Most of the electronic system manufacturers concentrate on improving reliability by having robust requirements and design, and by identifying failures and ways to avoid them. These steps, though very important, are not enough in order to achieve the high reliability goals. In order to shorten the length of the reliability test phase most manufacturers generally focus on reaching the point in the bath curve where the failure rate is constant. Then by interpolation they calculate the life time of the system and the failure rate. Typically manufacturers only discover the wear-out point by collecting field data and analyzing failed returned products. Not many manufacturers continue to test component or system sample groups in the lab in order to reach the wear out point. As a result, most manufacturers cannot guarantee the long operation life time of their systems or components, and only have interpolated failure rates achieved by calculation in their datasheets.

The essence of the SolarEdge approach to reliability is in a physics-based multi-level approach and identification of the failure points. Our goal is to achieve a proven 25 years system operational lifetime with a low failure rate, and the only way to achieve this is with a combination of reliability-oriented design rules, selection of top-tier suppliers and acceptance testing for their components, manufacturing in well-controlled environments and accelerated lifetime testing of the system (and its components) up to the wear-out point in order to determine when the product will fail, at what rate and the failure mechanisms at fault.

This goal is achieved by a multi-level reliability plan which is described in figure 2 (below).

Some of the advanced steps taken by SolarEdge are highlighted in the following sections

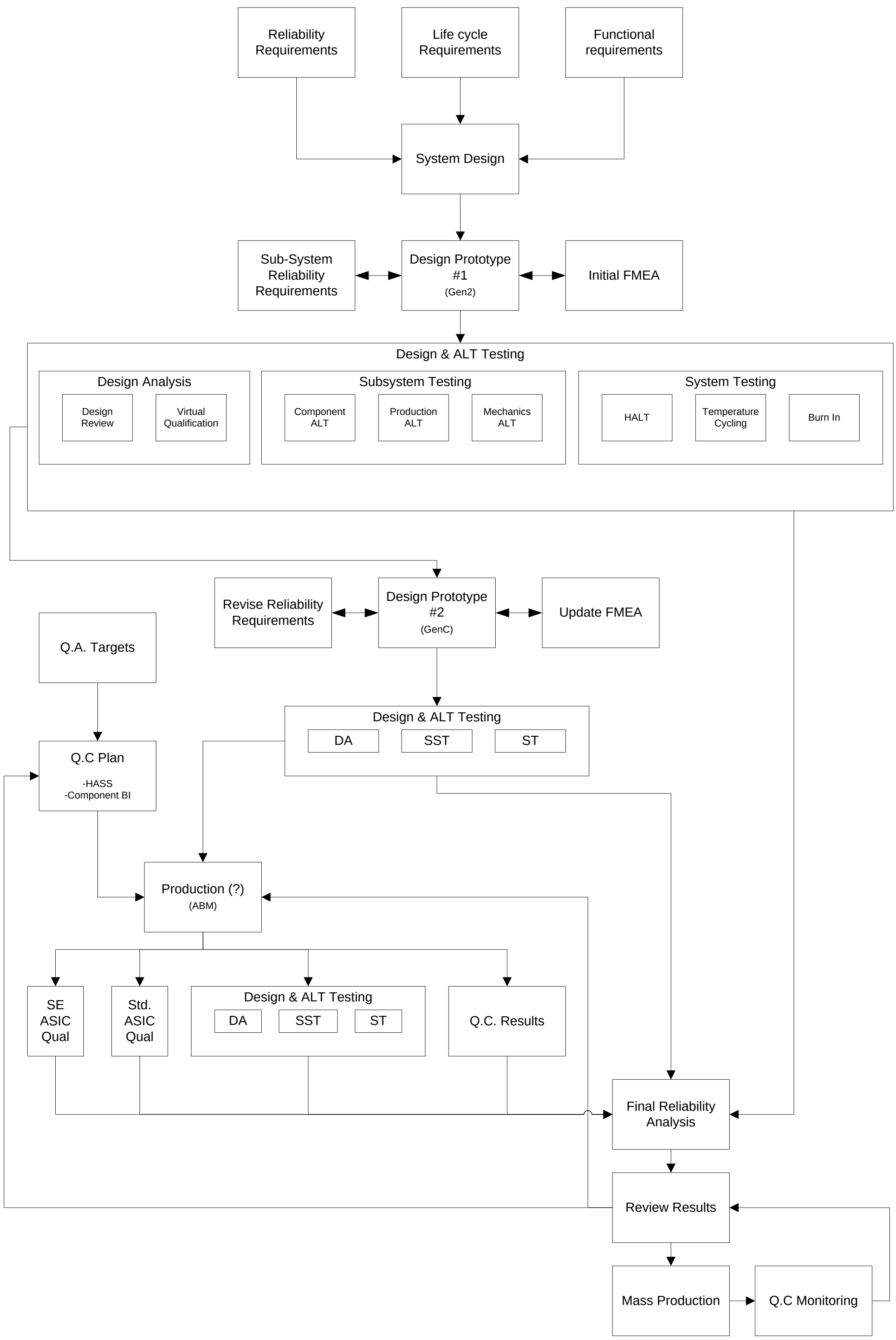

Figure 1- SolarEdge Reliability approach flow chart

Design

We believe that high reliability starts at the design stage. Each design starts with a failure mode, criticality, and effect analysis (FMECA) which identifies potential failure points and minimizes their effect. A thorough internal review is conducted, assuring that all components are functioning well within their specification according to SolarEdge's de-rating rules (which require 60-80% de-rating of maximum ratings allowed by the vendor). To assure that there are no thermal issues, finite-element thermal simulation and sensitivity analysis is performed on the product. In addition to the internal reviews done, there are a number of external reviews performed by objective third-parties: a Reliability Assessment by a leading design review firm provides best-of-breed insights on how to improve reliability, MTBF calculation provides a rough numeric estimate of the lifetime, Virtual Qualification is performed by the CALCE institute identifies weak points and Design for Manufacturing reports by Flextronics, a worldwide leading EMS, provides maintainability and manufacturability insights. Inputs from all of these sources are implemented in the design as an integral part of our iterative design process.

Example: A FMECA analysis performed on the power optimizer emphasized a number of components: (a) multilayer ceramic capacitors from 4 different vendors were subjected to accelerated stress tests in order to choose the one with best reliability performance. (b) Quartz crystals from 3 vendors were tested; as a backup, a ring oscillator was implemented in the ASIC to mitigate the effect of possible crystal failure. (c) An integrated bypass mechanism – which is physically separated from power train – was implemented to allow the PV string to operate even in case of extreme failure of a power optimizer.

Example 2: The initial design of the inverter included use of IGBTs of a certain shape (TO247). Following finite element thermal simulations and an external reliability review we identified that the heat dissipation of the IGBTs is the limiting factor of our design. In order to combat this issue, we redesigned the inverter’s heat sink in order to deal with IGBTs’ thermal stress – the heat-sink was re-shaped to provide better dissipation around the IGBT area, and the components themselves were enlarged to a TO264 package so they could be kept cool and have higher reliability. As a result, we were able to have the same design produce 20% more power, and do so at elevated ambient temperatures.

Component Selection

Before allowing any component into a SolarEdge product, a thorough analysis is performed on both the technology of the component and the vendor manufacturing it. Only tier-1 manufacturers are approved for use in the products, and reliability data and test reports must be provided by manufacturer before considering the product for use. However, with sensitive components the above checks are only enough for the component to be a candidate for use in the products. A number of candidates are selected, and for each candidate a large amount of components is purchased and put through rigorous stress testing. The testing is continued until reaching wear-out, and during it the components are sampled periodically for parametric measurements. Only the best performing components are approved for use in the product. All the components comprising the assemblies are with extended temperature performance and 100% tested by vendors.

Example: The capacitor banks used in the power optimizer require large capacitance. A technology survey was conducted, which disqualified the use of electrolytic or film capacitors, and approved the use of MLCC (Multilayer Ceramic) capacitor technology. To avoid mechanical failure due to thermal coefficient of expansion (TCE) mismatch, only flexible termination capacitors were approved.. In order to determine the part to use, over 30,000 capacitors were purchased from 4 leading vendors. These components were put in burn-in (at +125°C) and thermal cycling (-40÷+125°C) tests, and removed every 250 hours for performance measurements. After tests equivalent to over 100 years in the field a part was selected. However, the tests continue to run until reaching end of life of the components.

Example 2: As opposed to the ceramic capacitors used in the power optimizer, there is no choice but to use electrolytic capacitors in the inverters (due to the high capacitance needed). The Electrolyte in these capacitors tends to dry out over time, thus causing the capacitors to wear-out. Typically, electrolytic capacitors are the limiting factor of inverter lifetime. In order to assure we achieve extended lifetime, we developed a unique thermal model taking into account the temperature, voltage, and ripple current which stress the inverter in different locations around the globe, in order to estimate the life expectancy of the inverter. This model, which takes into account the benefits of low stress on the capacitors thanks to our unique system (due to fixed inverter voltage and large de-rating), has proven the inverter has a life expectancy of 18 years in harsh locations (and more than that in cooler places) and thus enabled us to provide a 12 year warranty on the SolarEdge inverters.

ASIC Development

A key element of our reliability strategy – and a significant differentiator relative to our competitors – is use of proprietary application specific ICs (ASIC) in our products. The best way to improve the reliability of electrical circuits is to reduce the number of components in it – this is done in SolarEdge products by replacing a large number of discrete components with a single ASIC designed specifically for the task at hand. The ASIC itself is manufactured with a fabrication process used for automotive-grade electronics (so operating temperatures are well within spec), and according to proprietary design rules specifically defined to allow for the long 25 year lifetime of the ASICs. Extensive analysis and testing has been done to assure the

ASIC packaging is robust enough to handle the mechanical and electro-chemical stresses experienced over 25 years of daily thermal cycling.

Example: Based on its excellent electrical and thermal performance a QFN (Quad Flat pack No Leads) package was initially selected for our ASIC. A theoretical literature survey on the long term reliability of QFN packaging raised concerns that mechanical stress from temperature cycles over 25 years may cause increased failure rates. Two parallel courses of action were taken in order to decide what package to use: In-depth simulations were performed in order to estimate the QFN life expectancy, taking into account different mechanical and physical parameters such as PCB design, solder selection and soldering process; Additionally, highly accelerated stress testing was performed on more than 1500 packages in a number of shapes so as to validate the simulation. Eventually, the QFN package did not reach the required reliability level and QFP package was selected for the ASIC.

Production and Sub-Contractors

Even with the best design and components, high reliability can't be achieved without reliable sub contractors and continuous quality assurance of the assembled products. In order to assure the quality of the sub-assemblies, a robust QA plan is in place, in which SolarEdge maintains quality control of all materials used, and samples of each part are taken for in-depth tests to assure the material composition and mechanical properties of the part. The final assembly is by a tier-1 global manufacturer in a test-intensive production process aimed to catch any failures before delivery to clients. Each circuit goes through automatic optical inspection (AOI), in-circuit testing with coverage of more than 90% (ICT), 100% functional testing, and extended burn-in testing with real time monitoring to identify early-life failures. Additionally, samples of each batch are taken for destructive and non-destructive testing.

System Integration and Field Testing

In order to make sure we fully understand the potential failure modes of our product, we make sure to get feedback from real-life tests and incorporate the lessons learned in the design. This is done by two means: large scale integrative reliability experiments, and in-depth failure analysis on samples returned from the field. Hundreds of modules are tested in various stress conditions: thermal cycling, burn-in, and damp heat stress testing is done in our thermal chambers for thousands of hours. Additionally, a power-cycling and testing with many different PV modules and environmental conditions is done across the globe. All failures encountered are independently investigated by reliability engineers, and field-data is continuously collected and analyzed from the hundreds of modules in the field. Failure analysis is conducted by reliability engineers with aid of tier-1 external labs in order to assure identification of failure root cause. Furthermore, Parametric testing of components extracted from field-tested circuits is performed in order to identify over-stresses and other potential issues which didn't lead to failure.

Example: Over 2000 power optimizers and 100 inverters have been built for beta testing before product mass production of which some were tested in various field locations world-wide and some were tested in accelerated life tests in SolarEdge labs and parametric tests. Analyses are performed on periodic basis to these units