Built-in Reliability into Power Electronic Systems

Review ECPE Workshop 25 – 26 June 2008 Toulouse, France

End of June 65 engineers and scientists came together to discuss progress made in power electronics reliability engineering. The applications focused on automotive, aerospace and railway power electronics. The new "Robustness Validation" process, which has been worked out by members of the automotive and supply industries under the umbrella of ZVEI, SAE, JSAE, was presented and discussed.

Prof. Eckhard Wolfgang (ECPE) has chaired the workshop together with Michel Mermet-Guyennet (Alstom PEARL) and Thomas Harder (ECPE).

The "Robustness Validation" handbook for components (J1879) is available since 04/2007, the handbook for modules and ECUs (J1211) is available since 6/2008 (see www.ZVEI.org/RobustnessValidation).

About twenty years ago Intel introduced the concept of building-in reliability. It basically means to control design, processes and materials which are used for producing chips rather than testing the chips itself. This concept is also very well suited to secure the reliability of power electronic systems. Today "zero defect" throughout the supply chain is a requirement. Everything has to be done right from the beginning, starting with the requirements concerning reliability and the mission profile.

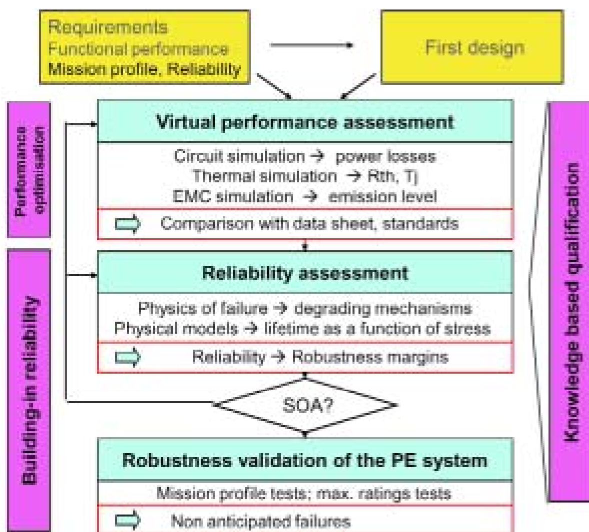

Figure1: The Robustness Validation workflow.

After having worked out a first design, the next step in the design process is "Virtual performance assessment" which includes electrical, thermal and EMI simulations. The results are compared with data sheets and standards. The next step is "Reliability assessment" based on the "physics of failure", and physical models for lifetime prediction. As a result the reliability margins are determined and a check is done if the design is within the safe operating area SOA.

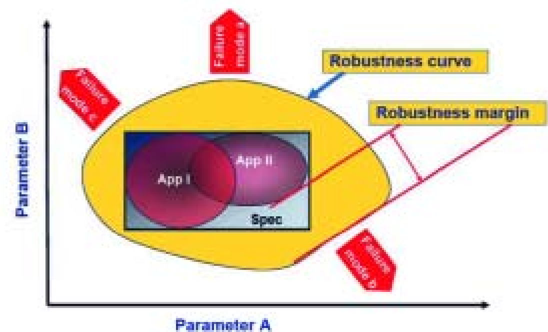

Figure 2: Robustness Diagramm, Example for 2 Parameters

The "Robustness validation" step includes end-of-life tests, mission profile tests and maximum ratings tests. The Robustness Validation process can be seen as an extension of the AEC Q100 test philosophy.

16 speakers, 12 from industry and 4 from the academia presented their most recent results according to the Robustness Validation process. Mission profiles for railway, automotive and aerospace were explained as well as the translation of the drive cycle of a hybrid delivery van to the stresses applied to the power module of the inverter and finally to the damage of bond wires due to driving the car. The mission profile includes all the stresses which are applied to the power electronics during the lifetime of operation. As an example for automotive applications the Robustness Validation Handbook describes the mission profile for a door module. It includes:

Door module service life; mounting location of the component/module; environmental loads like the climatic stresses, dust/water, chemical stress/resistance to media, mechanical stress (vibration, acceleration), random vibration, transport/storage/crash/assembly, electrostat-

ic discharge ESD, relevant functional loads. This example shows that the mission profile has to be done for every application and location in the car individually.

A major concern in designing a power electronic system is the variety of single CAD tools but there is no generic tool available to cover all disciplines necessary, like electric, magnetic, mechanical, thermal, thermo mechanical, EMI, computational fluid dynamics, etc.
The company EPSILON is developing a web-based tool which should allow short-time multi physics simulations. Examples were given for thermal simulations by Mauro Ciappa, ETH Zurich, for vibrational design by Christoph Barthes, Continental Automotive France SAS, and for EMI by Jean-Marc Dienot, Alstom PEARL Lab.

Patrick McCluskey from the University of Maryland who is responsible for power electronics reliability and high-temperature electronics explained the "physics-of-failure" approach and covered typical failure modes. In the field of high-temperature electronics he reported about the highlights of the IMAPS HiTEC conference, where he has served as technical chair. High temperature means operation temperatures above 125°C. Capacitors are particularly challenging components for reliable operation above about 300°C, since they exhibit variation with capacitance and dissipation factor. Among the different materials Teflon capacitors shows good temperature stability. Promising results are achieved for high-temperature and lead free die attach materials: Silver sintering and liquid phase sintering will certainly play an important role in the future. In a case study reliability data were shown by Uwe Scheuermann, Semikron, for the industry solderless power module. There is a high potential for increased reliability to be seen.

The other case studies dealt with automotive, railway and aerospace applications. An injection molded leadframe module was discussed by Jean-Michel Morelle, Valeo, using Cu/Al ribbons instead of Al wires for bonding.

Mauro Ciappa, ETH Zurich, discussed the very important but complex topic of lifetime prediction. He pointed out that the analysis of the thermal mission profile is very sensitive to the simulation results. Rainflow counting is one method but there is always a calibration experiment recommended.

Finally, intelligent testing was discussed by Michel Piton, Alstom Transport, and Gerard Coquery, INRETS. It is maybe the most serious challenge in the Robustness validation process because of the required end-of-life testing for determining the failure mechanism. Especially the acceleration for high-temperature power electronic systems is limited by e.g. melting of solders and phase changes of plastic materials.

At each day a panel discussion took place with a lively discussion. The dinner speech given by Lucien Prisse, Airbus France, showed the importance of a reliable power electronics for the vision of a more electric aircraft. In another dinner presentation, the DéciElec business convention for on-board systems was introduced which will take place on 28-29 April 2009 in Tarbes (www.decielec.com).

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