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Reliability assessment platform for the power semiconductor devices – Study case on 3-phase grid-connected inverter application

Ionuţ Vernica [a,*], Ke Ma [b], Frede Blaabjerg [a]

[a] Department of Energy Technology, Aalborg University, Aalborg, Denmark
[b] School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, Shanghai, China

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ABSTRACT

Because of the high cost of failure, the reliability performance of power semiconductor devices is becoming a more and more important and stringent factor in many energy conversion applications. Thus, the need for appropriate reliability analysis of the power electronics emerges. Due to its conventional approach, mainly based on failure statistics from the field, the reliability evaluation of the power devices is still a challenging task. In order to address the given problem, a reliability assessment platform is proposed in this paper. An advanced reliability design tool software, which can provide valuable reliability information based on given mission profiles and system specification is first developed and its main concept is presented. In order to facilitate the test and access to the loading and lifetime information of the power devices, a novel mission profile based stress emulator experimental setup is proposed and designed. The link between the stress emulator setup and the reliability tool software is highlighted. Finally, the reliability assessment platform is demonstrated on a 3-phase grid-connected inverter application study case.

1. Introduction

Nowadays, grid-connected inverters are widely used in many mission critical applications such as, wind power generation, photovoltaics, energy distribution systems or motor drives. Due to their essential role within power systems, the reliability of the power converter is one of the main factors that influences the overall efficiency and cost of the system.

Consequently, numerous studies have been carried out in order to determine the main causes of failure in power converters, and it has been concluded that the power devices represent the most fragile components of the power electronics system, with respect to reliability [1,2]. According to [3], the predominant source of stress for the power devices is the steady-state and cyclical temperature variation, which can result in some of the most common failure mechanisms in power modules: bond wire lift-off and solder crack [4,5]. The unexpected wear-out failures of the power semiconductors will lead to an increase in maintenance cost, and a cutback in the total energy production of the system (due to downtime), and thus resulting in a higher cost of energy conversion.

As shown in Fig. 1, the conventional reliability improvement approach of power converters is mainly based on the failure information and statistics from the field. Due to the fact that this method is expensive and time consuming, the need for prior reliability assessment, during the design and development phase, arises. Thus, by introducing a reliability evaluation tool within the initial phases of the product life cycle, as presented in Fig. 2, the weaknesses and lifetime of the power converter can be identified before introducing the product into the market. This tool will help to optimize the design of the power converter in order to achieve a better balance between reliability and cost, and finally result in a significant cost reduction in the whole lifetime cycle of the product.

In this paper, a reliability assessment platform consisting of a reliability evaluation tool and a stress emulator experimental setup is proposed. Initially, the main concept of the reliability tool will be introduced and a brief description of the models used within the tool will be given. Afterwards, the stress emulator setup and its operating principle and capabilities will be presented. Finally, a study case of a 3-phase grid-connected inverter application will be demonstrated.

2. Reliability tool for the design of power electronics

The reliability tool has been developed based on MATLAB and Simulink, and allows for fast and straightforward reliability assessment of the power devices according to the input mission profiles and system specifications. The tool is built in a generic manner, and thus allows various power conversion applications to be implemented (e.g. wind power generation systems, photovoltaics, motor drive, etc.). The general

* Corresponding author.
E-mail address: iov@et.aau.dk (I.ţ Vernica).

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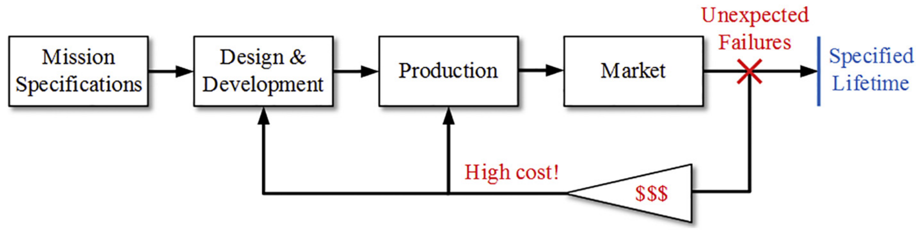

Fig. 1. Conventional reliability assessment flow.

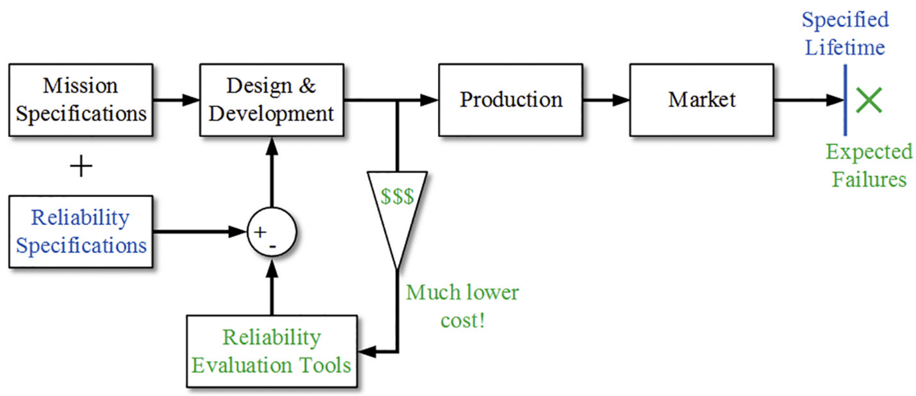

Fig. 2. New and improved reliability assessment flow.

flow and structure of the tool for the given 3-phase grid-connected inverter application study case is presented in Fig. 3.

As it can be seen in Fig. 3, the tool employs the multi-timescale modelling concept [6], which allows the integration of the different time-constant of the system, ranging from microseconds (device switching) to days (environmental temperature variations). In order to assure a better understanding, a brief description of the models used in the tool will be given in the following.

2.1. System-level modelling

A typical 3-phase 3-level Neutral Point Clamped (NPC) grid-connected inverter application is chosen as the study case, as shown in Fig. 4. The inputs to the system are the DC-link voltage and DC current mission profiles, while the switching sequence of the active semiconductor devices is assured by means of Space Vector Modulation (SVM) technique. Additionally, an LCL filter is used in order to cancel-out the unwanted harmonics on the grid-side. In this paper, the lifetime investigation will be carried out only for the upper transistor (T_1) of the NPC power module 30A 1200 V.

The system-level dynamic behaviour of the converter, resulting from running the tool, is shown in Fig. 5, where a constant DC link voltage and a step (5A → 15A) in the DC current mission profiles are assumed.

The large signal model of the converter has been build and integrated within the reliability tool.

2.2. Component-level modelling

The electrical outputs of the converter large signal model, such as, duty ratio (d_{abc}) or the grid phase currents (i_{abc}), will represent the inputs to the component-level block, in which the power loss and thermal model of the power device are implemented.

The power losses generated by the power semiconductors have been modelled based on the conduction and switching loss equations [7].

Additionally, due to the dependency between the loss characteristics and temperature [8], the junction temperature of the power devices has been included as a feedback from the thermal model. It should be noted that all the necessary parameters for building the average switching cycle power loss model can be extracted for the device characteristics

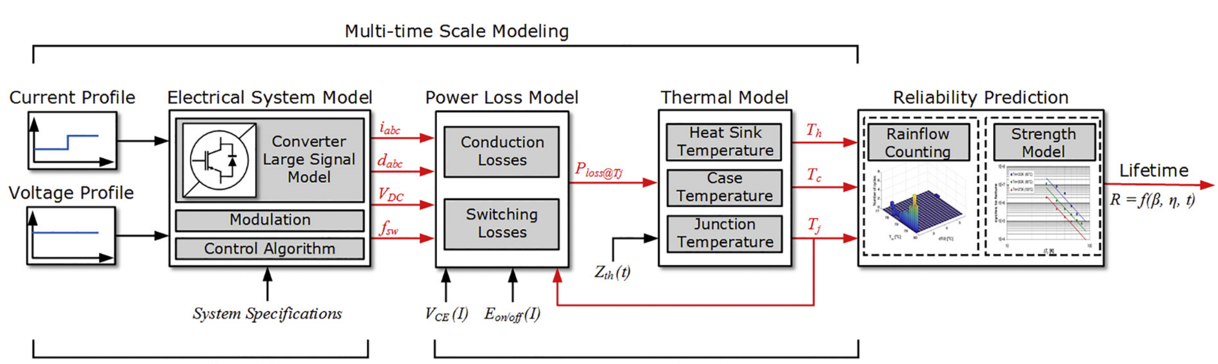

Fig. 3. General flow and structure of the tools for 3-phase grid-connected inverter application.

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