Unconventional approach for aging monitoring based on S-parameters analysis

Start time possible at any time in 2024 (November expected)

Supervising team

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Applications

- Address all correspondence to: paul-etienne.vidal@uttop.fr and stephane.baffreau@uttop.fr
- Opening of applications: September 1st 2024
- End of applications: as time goes by 31 October 2024. Note that the selection process will be done over the application period.
- After a selection phase based on received files, video auditions will be held upon invitation
- Start of contract: at any time according to negotiation
- Send:
  - a **detailed CV and cover letter** detailing how your experience target expectations.
  - a **MASTER score synthesis** for 1st and 2nd year,
  - a **contact details** of a reference person.

Context

The PhD subject is part of the SAFEPOWER European project, particularly concerning the rise in sustainable, competitive, and secure Medium Voltage DC (MVDC) converters.
Electrification and the widespread adoption of renewables are crucial for achieving deep decarbonization, promoting a sustainable energy transition, and reducing the EU's reliance on Russian fossil fuels (REpowerEU) [1], [2] and [3]. The growing demand of electric energy also driven by electrification underscores the pressing need for a more efficient, secure, flexible, and affordable energy distribution in the foreseeable future[4]. In this context, Medium Voltage Direct Current (MVDC) grids are decisive. They are instrumental in facilitating the deployment of renewables, especially solar plants [5], across Europe, ensuring regional coverage within countries in a range of a few hundred kilometers. In this distribution, MVDC converters, operating with direct current (DC) at medium voltage levels (1-35 kV) and handling DC/DC, AC/DC and DC/AC conversions, perform essential functions such as voltage transformation to align with various loads connected to the grid. They contribute to power control and management, regulating voltage, current, and power flow for

grid stability and reliability. Therefore, enhancing security, reliability, resilience and affordability of MVDC converters is pivotal for advancing Europe's energy transition.
In this scenario, SAFEPOWER first explores and investigates on essential digital, enabling, and emerging technologies to achieve a new generation of MVDC converters:
i) capable of anticipating failures to prevent downtime using effective Condition and Health Monitoring (C&HM) solutions (online and offline) assisted by artificial intelligence (AI) strategies,
ii) based on more compactly-packaged, efficient, rugged and affordable Silicon Carbide (SiC) power MOSFETs, diodes and JFETs for DC breakers with a more sustainable manufacturing, and
iii) prospecting on Ga2O3-based emerging power devices (MESFETs, diodes and JFETs for DC breakers) especially designed for this application. This PhD subject addresses the first items by developing an innovative approach for monitoring the power electronic devices aging, through S-parameters analysis. The unconventional approach is based on previous research conducted by the e-ACE² research group [6]. This unconventional non-destructive testing method employs Radio Frequency characterization to investigate impedance changes and will be applied to various aging processes, including thermal cycling, active power cycling, and overvoltage stresses.

Scientific question and scientific objective

Based on the unconventional Nondestructive characterization, is there a generic failure indicator that makes possible to evaluate the healthy state of a power electronics discrete packaging (converter leg) during aging test? Is this generic failure indicator able to predict the end of life of such a device. The scientific objective is to investigate such an approach, with 3 aspects:

- define a generic failure indicator applied to a power electronic discrete packaging: target 1;
- evaluate the ability of this generic indicator to predict end of life: target 2;
- develop an online monitoring by the means of a specific and real-time electronic circuitry: target 3;

Scientific / technological challenges

The first scientific challenge concerns the definition of a failure indicator being able to monitor several failure degradations.
The second scientific challenge, which can be seen as a sub-issue of the first, consists of evaluating the end of life of this device using a generic failure indicator.
The second technological challenge is the definition of an experimental setup and the associated testing procedure that will be applied on power electronics discrete packaging. The setup should be generic to be used by several SAFEPOWER partners.
The second technological challenge concerns the development of an offline monitoring by means of specific and real-time electronic circuitry.

Delivrables and milestones

Delivrables

- L1: A design and technical report that details configuration, implementation and procuration of all the necessary elements for the experimental test bench associated with its specific characterization interfaces.
- L2a: A report including the presentation and analysis of the results of experimental aging and characterization tests.
- L2b: A state of the art report about S-parameter characterization applied to packaging health-monitoring, and its use for a Failure Indicator.

- L3: A specific and real-time electronic circuitry (CAD + prototype) to perform an on-line monitoring
- L4: A scientific article in an international journal (at a minimum).
- L5: A thesis manuscript and a defense presentation.

Milestones

- J1: State of the art.
- J2: Definition of a generic failure indicator and application to predict the device end of life.
- J3: Design of a specific and real-time electronic circuitry.
- J4: Orally present partial results in a national conference and an international conference.

Workplan (provisional)

The work proposed in this subject aims to characterize the heathy state of a Medium Voltage Direct Current converter using non destructive testing. This work must be supplemented by the observation and quantification of failure detection in order to design and implement a dedicated online monitoring system based on electronics circuitry. To achieve these objectives, the work is organized into 4 tasks:

- T1: Bibliographic analysis of non destructive power electronic characaterization;
- T2: Wide frequency band experimental characterization of the power module;
- T3: Generic failure indicator definition and evaluation of end of life;
- T4: Design of an online monitoring by a specific and real-time electronic circuitry

In the first task, T1, the work will consist of providing a state of the art characterization methods over a wide frequency band of power modules using wide gap power semiconductor components. This bibliographic analysis should give rise to a definition of a generic failure indicator which should make it possible to predict the end of life of power components. A proposal relating to the design and production of a demonstrator, to monitor online and real-time the healthy state of the power module, would ideally finalize this first task.

The second task, T2, will concern the wide frequency band experimental characterization of the power module. This will involve experimentally determining all of the RLC parameters constituting the power module: from the parasitic elements of the wide gap semiconductor components to the interconnections of the demonstrator case. These experiments will mainly be based on the use of a vector network analyzer and will require the development of specific characterization interfaces.

The third task, T3, will consist of defining a S-parameter based's generic failure indicator to detect the main well known failure mechanisms due to stockage, passive and active conditions of MVDC converter. This crucial step will thus make it possible to try to predict the end of life of a such power module.

The final task, T4, will consist of designing an online monitoring by means of a specific and real-time electronic circuitry. Ideally, this task will be achieved by a validation of the hardware monitoring on MVDC converter demonstrator in experimental conditions.

References

[1] ETIP-SNET, Ed. Eric Bacher et al. 2018.
[2] X. Jordà et al., "Challenge 4: industry electrification and grid management", vol. 8 Clean, Safe, and Efficient Energy, White Papers. CSIC Scientific Challenges: Towards 2030, pp. 97-100, 2021.
[3] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483, last visit 18/08/2024.
[4] ETIP. "ETIP SNET R&I Roadmap 2020-2030". Ed. Eric Bacher et al. 2020.
[5] https://energy.ec.europa.eu/system/files/2022-05/COM_2022_221_2_EN_ACT_part1_v7.pdf, last visit: 10/01/2024.E. Gurpinar et al., "SiC MOSFET-Based Power Module Design and Analysis for EV Traction Systems," 2018 IEEE Energy Conversion Congress and Exposition (ECCE), Portland, OR, USA, 2018, pp. 1722-1727, doi: 10.1109/ECCE.2018.8557609.
[6] A. Gopishetti, S. Baffreau, P.-E. Vidal, C. Duchesne, T.L. Long,Brazing failure of inner power modules' interconnects using scattering parameter characterization, Microelectronics Reliability,Volume 150,2023,115116,ISSN 0026-2714,https://doi.org/10.1016/j.microrel.2023.115116.

Profile

The candidate must have a scientific background specializing in electronics / radio frequency / electrical engineering. In addition to proven technical qualities, the candidate must have scientific curiosity to tackle the different stages proposed but also be proactive in the conduct of the study. Good mastery of the characterization tests of electronic cards would be an advantage. Mastery of Scilab and/or Matlab/Simulink software, coupled with knowledge of LTSPICE/PSPICE type circuit software is important. Experience in characterizing S parameters using a vector network analyzer or the use of software tools such as ADS or ORCAD would be an additional asset. The candidate will have qualities in terms of human relations to carry out interactions with several experts who will help its work.
The candidate must also have a good level in English language and written and oral communication and synthesis skills. Let us note that same skills in French are welcome. Ideally, the candidate will either be at the end of their Research Master course, or will have accumulated one to two years of experience after their Research Master course.

Place of the work

The work will mainly take place at 2 places, located at 5 km from each other:

- Production Engineering Laboratory, Université de Technologie de TARBES (Technology institute of Tarbes), 47 Avenue d'AZEREIX, 65000 TARBES;
- PRIMES platform, 67 Boulevard Pierre Renaudet, 65000 TARBES. This address will be the main location of the study.

Different missions in European Union are scheduled. They are funded by the projects.

Funding

The thesis subject is part of the SAFEPOWER European project, particularly concerning the rise in sustainable, competitive, and secure Medium Voltage DC (MVDC) converters.
The doctoral student will benefit from funding from this European project for a period of 36 months. Net monthly salary reference €1,700.

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