Master project, 2021-2022

High-Current Power Converter using GaN Devices

Supervisor : Arnaud VIDET, L2EP – Univ. Lille
Email: arnaud.videt@univ-lille.fr

Context

Electrical energy is managed by power electronics converters in a wide range of applications including solar charge controllers, battery chargers (e.g. portable devices, e-mobility), uninterruptible power supplies (e.g. data centers), actuators controls and motor drives (aircrafts, electric transportation, industrial applications). Especially, installed power electronics onboard vehicles is rapidly increasing, as the whole European automotive market is expected to include some sort of electrification from mild hybrid to fully electrical vehicles by 2030 [1], calling for numerous power converters such as on-board battery charger, motor drive inverter, and DC/DC converters (Figure 1). This huge demand for power electronics will be driven by the technological breakthrough of new power devices such as SiC and GaN components that will supersede the conventional silicon ones. Indeed, improvement of power electronics technology is a strategic focus towards smaller power losses and reduced converter volume and mass, which saves vehicle consumption and useful space to increase onboard stored energy, resulting in improved overall energy efficiency and mileage of electric vehicles.

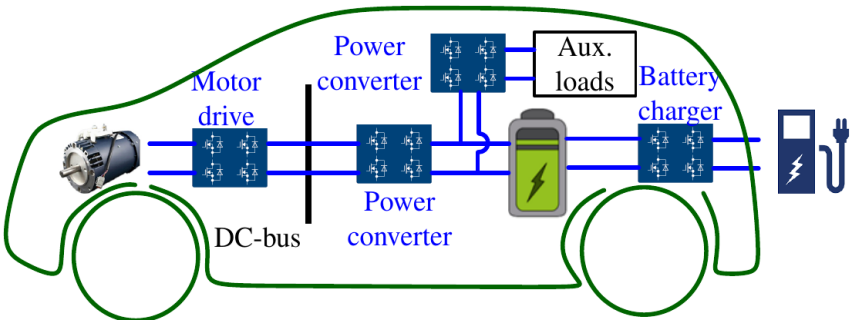

Figure 1: Power converters in an electric vehicle [3]

The Power Electronics team of the L2EP laboratory develops a research activity based on the new switching power devices, especially GaN components that are now commercially available and offer the best performance in a voltage range that is suitable for e-mobility applications. Various works focused on the characterisation [2-4], modeling [5,6], and implementation constraints [7] of GaN devices so as to fully benefit from their outstanding electrical performance and improve the converters energy efficiency and power density. Further, GaN devices are currently being used to build laboratory prototypes of integrated motor drives into an electrical machine [8-10], which can benefit to automotive applications.

Objectives

While GaN devices allow significant improvements of power density in future power electronics converters, their small size involve more constraints on thermal management and layout optimisation, especially for high-current applications that require additional techniques such are multiple-devices paralleling in constrained-size area. This raises new issues such as gate-drive length balancing or circulating currents that may cause instabilities and thereby reliability concerns. Thus, design rules must be considered, notably by taking attention to unequal parasitic inductances due to layout and geometric constraints.

This internship proposal aims at supporting the ongoing research of the Power Electronics team by extending the use of GaN power switches to high-current applications involving parallelling of surface-mounted GaN devices in printed-circuit boards. Electrical, thermal and geometric constraints will be taken into account to optimise the placement and utilisation of GaN power devices for these applications. The laboratory electrothermal device models and stray inductance extraction procedures will be used to highilight the possible gate balancing and stability issues, so as to determine an optimised solution that will be validated through both simulation and experimental measurements carried out on a specific modular test bench.

Using GaN devices in power conversion is currently a hot research topic as can be appreciated from the reference list including recent publications from L2EP members. Accordingly, this master project will likely come in support of a PhD thesis in L2EP laboratory in collaboration with Coventry University, UK, that will focus on the design of GaN-based power converters for e-mobility [11].

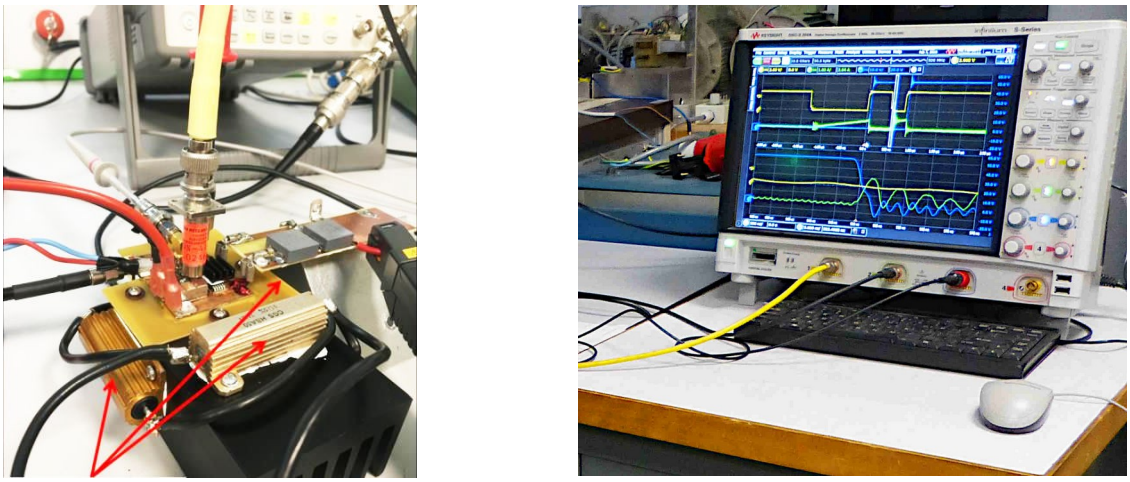

Figure 2: laboratory measurements on a GaN-based power converer

Schedule

Interested candidates can apply by e-mail at arnaud.videt@univ-lille.fr to request an appointment. Latest transcripts may be provided. Useful skills to succeed in this project are solid scientific background and willingness to learn an area of electrical engineering by focusing on devices that assemble into a functioning system, with extensive experimental and simulation parts of power electronics converters. Preliminary experience in electric circuit simulation or CAD design is appreciated but not mandatory. Expect a few technical questions to evaluate the match with this project and adapt the working progress in an efficient way.

If the application is selected as part of the master thesis program, then preliminary works will be proposed in the first few months to gradually acquire specific knowledge on the subject. It includes a bibliographic study focusing on state-of-the-art GaN devices, converters and test setups, and an intermediate scientific project related to experimental instrumentation or power losses estimations by simulation. Consequently, the full-time internship in the second semester will take benefit from the former projects and continue toward the aforementioned objectives. The work will take place in the ESPRIT building of the University.

References

[1] *"Les priorités technologiques de la filière automobile et mobilités"*, Plateforme automobile (PFA) roadmap, pp. 4–5, retrieved 07/2020, url: https://pfa-auto.fr/wp-content/uploads/2020/07/feuille_de_route_pfa_version_finale_10h27.pdf

[2] *"Extraction of Packaged GaN Power Transistors Parasitics Using S-Parameters"*, L. Pace, N. Defrance, A. Videt, N. Idir, J-C Dejaeger, *IEEE Transactions on Electron Devices*, Vol. 66, N°. 6, pages. 2583-2588, 04/2019, https://doi.org/10.1109/TED.2019.2909152

[3] *"Experimental Investigation of GaN Transistor Current Collapse on Power Converter Efficiency for Electrical Vehicles"*, K. Li, A. Videt, N. Idir, P. Evans and M. Johnson, *2019 IEEE Vehicle Power and Propulsion Conference (VPPC)*, Hanoi, Vietnam, 10/2019, https://doi.org/10.1109/VPPC46532.2019.8952479

[4] *"Accurate Measurement of Dynamic on-State Resistances of GaN Devices Under Reverse and Forward Conduction in High Frequency Power Converter"*, K. Li, A. Videt, N. Idir, P. L. Evans and C. M. Johnson, *IEEE Transactions on Power Electronics*, vol. 35, no. 9, pp. 9650-9660, Sept. 2020, https://doi.org/10.1109/TPEL.2019.2961604

[5] *"Modelling GaN-HEMT Dynamic ON-state Resistance in High Frequency Power Converter"*, K. Li, A. Videt, N. Idir, P. Evans and M. Johnson, *2020 IEEE Applied Power Electronics Conference and Exposition (APEC)*, New Orleans, LA, USA, 03/2020, https://doi.org/10.1109/APEC39645.2020.9124513

[6] *"Electrothermal Modeling of GaN Power Transistor for High Frequency Power Converter Design"*, L. Pace, F. Chevalier, A. Videt, N. Defrance, N. Idir, J.-C. De Jaeger, *2020 22th European Conference on Power Electronics and Applications (EPE'20 ECCE Europe)*, Lyon, France, 09/2020

[7] *"Analysis of GaN Converter Circuit Stability Influenced by Current Collapse Effect"*, A. Videt, K. Li, N. Idir, P. Evans and M. Johnson, *2020 IEEE Applied Power Electronics Conference and Exposition (APEC)*, New Orleans, LA, USA, 03/2020, https://doi.org/10.1109/APEC39645.2020.9124351

[8] *"Integrated Smart Energy Converter"*, Projet CE2I, Contrat de Plan État-Région, http://ce2i.pole-medee.com

[9] *"Modeling and Experimental Analysis of a Single Leg towards the Design of an Integrated GaN Converter"*, S. Vienot, H. Hoffmann, A. Videt, T. Duquesne, N. Idir, *25th Symposium on Electromagnetic Phenomena in Nonlinear Circuits (EPNC)*, Arras, France, 06/2018

[10] *"Design of an Integrated GaN Inverter into a Multiphase PMSM"*, F. Salomez, S. Vienot, B. Zaidi, A. Videt, T. Duquesne, H. Pichon, E. Semail, N. Idir, *submitted in 2020 IEEE Vehicle Power and Propulsion Conference (VPPC)*, Gijón, Spain, 10/2020

[11] *"Design of GaN-based Power Converters for Electric Mobility"*, PhD project starting late 2020, url: http://l2ep.univ-lille.fr/wp-content/uploads/Sujet_these_EDSPI-2020-EP.pdf