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DC-DC converters for electric vehicle applications

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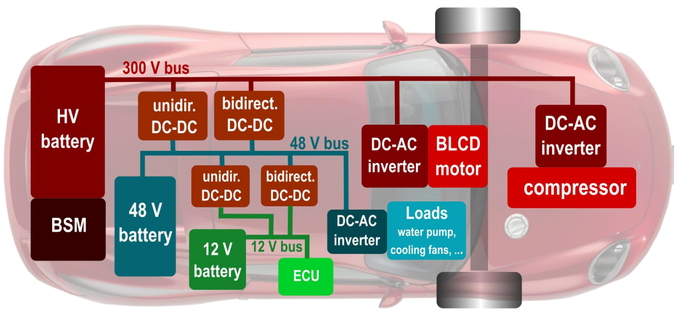
Research context and motivation

Purely electric vehicles (EVs) and Hybrid electric vehicles (HEVs) are expected to reach 5% and 20 % of sales worldwide by 2025, respectively. In particular, the power architecture is completely different compared to standard internal combustion engine vehicles, since the HV lithium battery powers both the traction inverter and the compressor, whereas medium and low-power loads are connected to the 48 V bus. Thus, unidirectional and bidirectional DC-DC converters are definetely required. Power converters used in automotive applications should be designed to achieve reliability, high efficiency, minimum weight and cost. The exploitation of Wide-Band Gap semiconductor, i.e. SiC and GaN power transistors, can ease the design in terms of higher power density and higher breakdown voltage, however the driving of such devices is a key point to achieve the aforementioned goals.

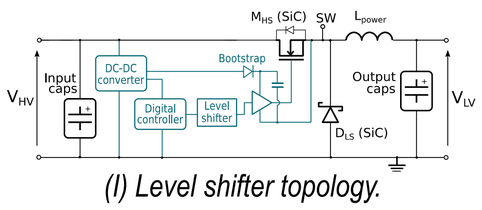
Addressed research questions/problems

DC-DC converters are required to transfer energy between different voltage buses. i.e. high-voltage (300 V), medium-voltage (48 V) and low-voltage (12 V). In particular, high-side power transistors are needed, regardless of the adopted topology, and should be driven to behave, ideally, either as an open or a short. For the sake of simplicity, a standard buck converter was considered. The driver of the high-side transistor has to be referenced to its source terminal, however, in a buck converter, such node swings from ground up to the input voltage. On the other hand, the control stage is typically referred to ground.

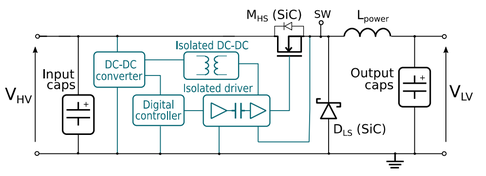


Popular solutions to address such issue are: I. Level-shifter, II. integrated isolated gate driver, III. pulse transformer. Neverthess, each of them suffers from critical aspects which may limit their application in automotive enviroment.

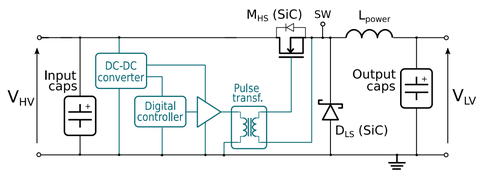
Driver topology	Pros	Cons
Level shifter	Integrated using standard process.	No galvanic insulation, isolation voltage up to 1200 V (SOI-CMOS).
Integrated isolated gate driver	Integrated couplers are already on the market.	Time Dependent Dielectric Breakdown affects reliability, insulated power supply may be required.
Pulse transformer	galvanic isolation, it is traditional solution when high voltage insulation has to be met.	No low-profile, physical dimensions not negligible to comply with safety standards.



(I) Level shifter topology.



(II) Integrated isolated gate driver topology.

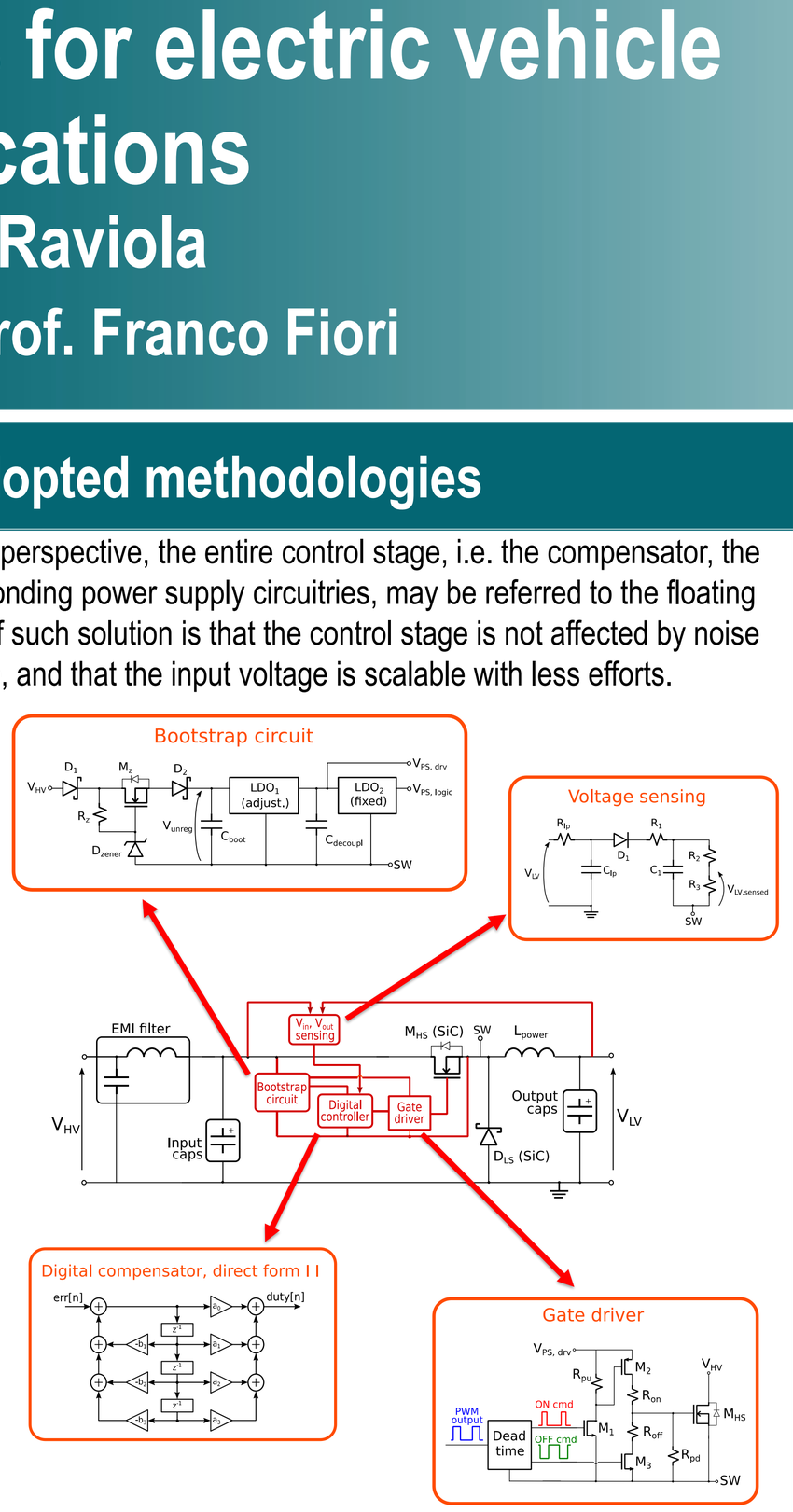


(III) Pulse transformer topology.

Adopted methodologies

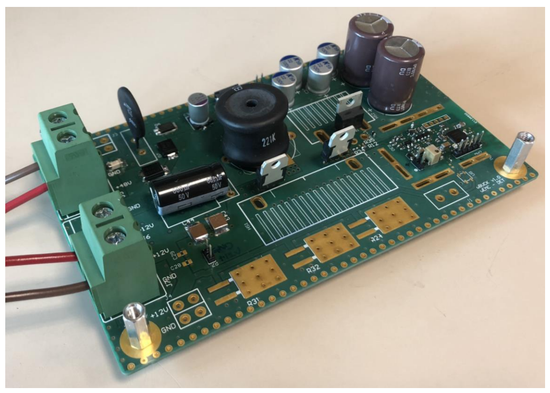
Approaching from a different perspective, the entire control stage, i.e. the compensator, the gate driver and their corresponding power supply circuitries, may be referred to the floating node. The main advantage of such solution is that the control stage is not affected by noise coming from the power stage, and that the input voltage is scalable with less efforts.

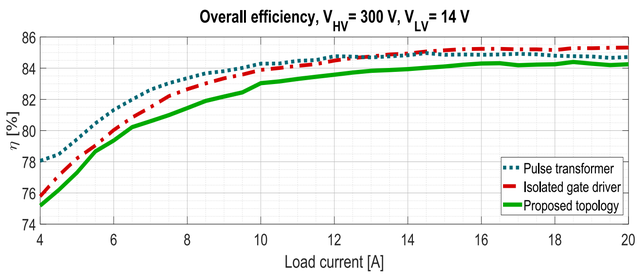
The proposed system consists of an input protection network, a differential mode EMI filter and the buck converter itself, plus the floating stage, which includes the bootstrap circuit, a microcontroller acting as digital compensator, the gate driver, input and output voltage sensing, plus the high-side current sensing. In particular, the compensator is implemented by the uC using a IIR filter, with the coefficients evaluated using the Tustin method from the analog transfer function.

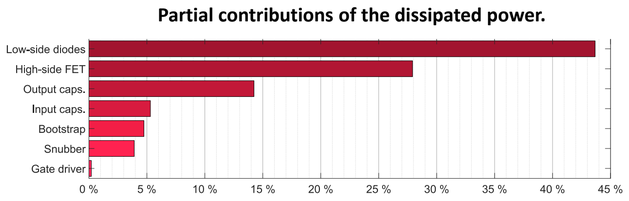


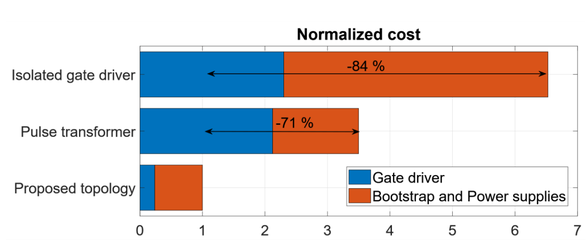
Novel contributions

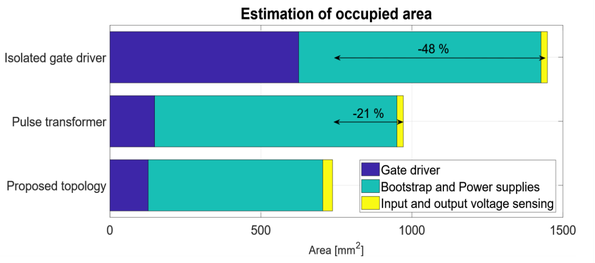
The proposed floating control stage was implemented at PCB level for a 48V-12V buck converter, capable of the providing the load with a 200 W output power. The entire floating stage, which consists of the aforementioned block, is entirely implemented using discrete components, and occupies an area of 34 *mm* x 22 *mm*.











Moreover, a 300V–14V buck converter, which exploits SiC devices, was designed and simulated. Adopting the proposed solution, the efficiency of the converter is in agreement with standard high side driver topologies. However, the estimated cost and occupied area are significantly lower, i.e. -80% and -48%, respectively, with respect to classic high-side driver.

List of attended classes

- 02LWHRV Communication (04.09.18, 1 credit)
- 01SHMRV Entrepreneurial Finance (31.08.18, 1 credit)
- 01MNFIU Parallel and distributed computing (27.06.18, 5 credits)
- 01SFURV Programmazione scientifica avanzata in matlab (20.04.18, 4 credits)
- 08IXTRV Project Management (04.09.18, 1 credit)
- 01RISRV Public speaking (19.07.18, 1 credit)
- 01SWQRV Responsible research and innovation (14.09.18, 1 credit)
- 02RHORV The new internet society (14.09.18 ,1 credit)
- 01SHFRO Vibration Based Statistical Methods (26.10.18, 2 credits)
- 01TETRU Forensic Metrology (21.03.19, 4 credits)
- 01SYBRV Research integrity (02.09.19, 1 credit)
- 01LEXRP Strumenti e tecnologie per lo sviluppo (12.09.19, 5 credits)
- 02LPNOQ Power electronics (18.09.19, 6 credits)

Submitted and published works

- Raviola, E. , Fiori, F., "*Real-time defect detection of wheel bearing by means of a wirelessly connected microphone*", 14th Conference on PhD Research in Microelectronics and Electronics, Prague, 2018, pp. 233-236
- Quitadamo M.V., Raviola, E. , Fiori, F., "*A Criterion for an Optimal Switching of Power Transistors*", 12th International Workshop on Electromagnetic Compatibility of Integrated Circuits, Haining, 2019
- Raviola, E. , Fiori, F., "*A High Voltage Dc-Dc Converter for HEVs with a Novel Floating Control Stage*", International Conference On Power Electronics, Control & Automation, New Delhi, 2019
- Quitadamo M.V., Raviola, E. , Fiori, F., *"Investigation on the Switching Waveforms of GaN Power Devices to Gate Current Profiles*", International Conference On Power Electronics, Control & Automation, New Delhi, 2019

Future work

- Experimental measurements to assess the proper functioning of the 48V-12V buck.
- Prototype and validate the 300 V -12 V step down dc-dc converter with the same floating control topology.
- An effective way to drive the low-side switch in order to increase the efficiency.
- Enable controlling and monitoring functionalities using a dedicated communication link capable of transferring data from the floating control stage.

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