ScuDo

Scuola di Dottorato ~ Doctoral School

WHAT YOU ARE, TAKES YOU FAR

XXXVII Cycle

Advanced solutions for integrated DC/DC converters' analysis and design

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Research context and motivation

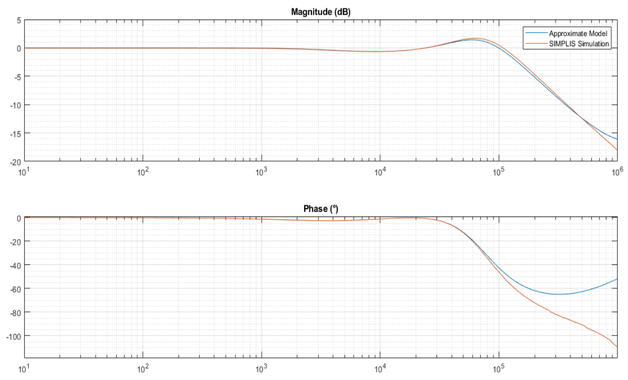
- The research context covers the analysis, modelling and design of advanced switching DC/DC power converters topologies.
  These topics are mainly driven by pressing need of both reducing the devices' energy consumptions and speeding up the vehicles' electrification process in the automotive sector, which requires high level of *quality*, *reliability* and *performance*.
  Targeting so distinct specifications with so stringent requirements and short products' time to market can't made possible without the proper description strategy for the main control topologies adopted in the DC / DC conversion systems, which further enables the possibility of identifying innovative and optimized solutions for the relevant points at issue.

- The constant growth in complexity of the converters' control architectures has posed new challenges in describing *analytically* the DC/DC dynamic behavior and the system performance since the design development and system verification's phases, making it difficult to extract a unified and general approach.
  Depending on the specific converter's topology, finding the most suitable system modelling strategy allows to provide the circuit designer an analytical tool accurate enough for practical purposes (e.g., highlighting any critical issue and the possible room for improvement), making the whole design flow faster and more reliable.

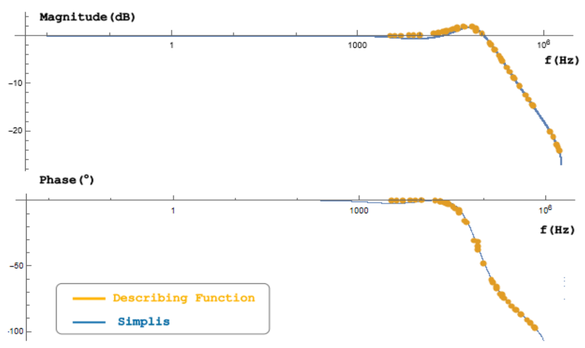
- Any DC/DC SMPS (in particular, for automotive) must comply with EMC international regulations standards. Active filter methodologies are effective in mitigating EMI disturbances with significant size and cost advantage.

Novel contributions

- Developing the analysis of more complex and realistic DC/DC converter topologies, such as the Enhanced V2 A-COT, exploiting the Describing Function (DF) technique.
  Depending on the frequency range of interest, a proper model has been derived.

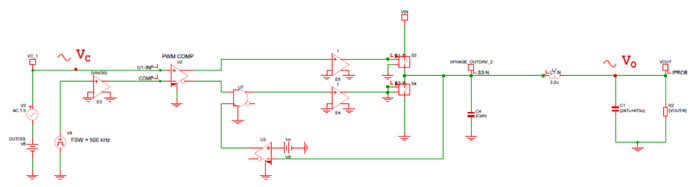


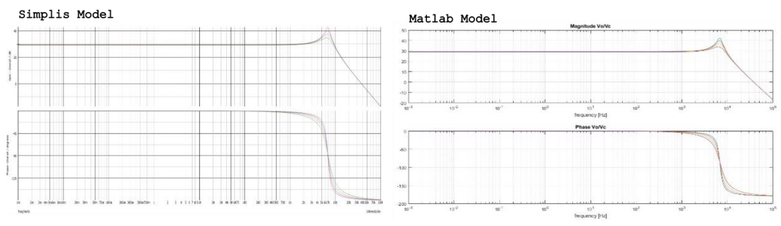
Low frequency model



High frequency model

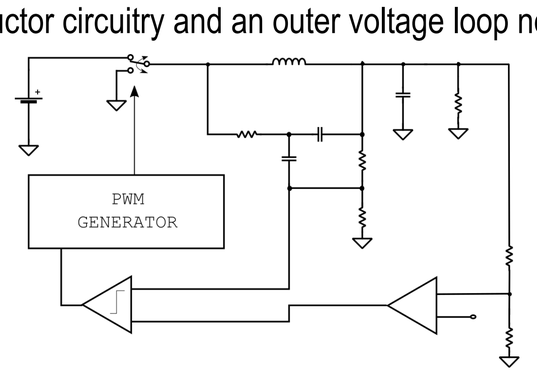
- A small-signal model which includes both the parasitic capacitance and the ZCD phase comparator has been derived exploiting the State Space Averaging (SSA) technique, tracking properly the input voltage variations.



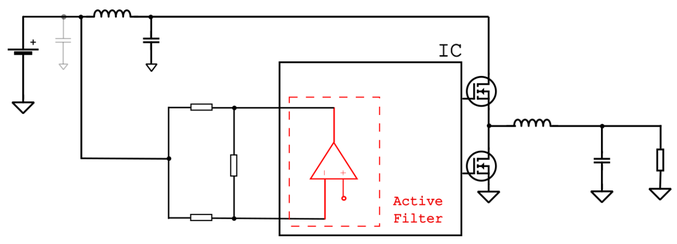


Addressed research questions/problems

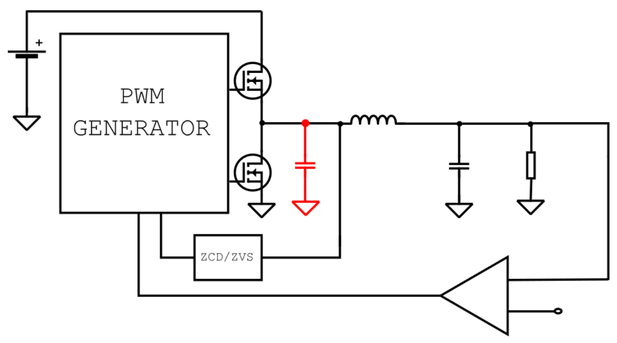
- **Enhanced V2 A-COT**: To extract a small signal model for a Constant-On-Time regulator which includes an inductor ripple reconstructor circuitry and an outer voltage loop network which improves the overall accuracy. In steady-state CCM, the A-COT behavior is much more independent with respect to operating condition (e.g., input voltage V_{IN} and V_{out}) compared to a standard COT.



- **Active EMI Filter:** To design an on-chip active EMI filter which allows to reduce the differential-mode conducted emission of a SMPS, injecting a counter phase signal which minimize the overall disturbance on the input line.
  The external sensing and injecting network replaces one passive filtering capacitance, reducing the overall size, volume and cost.



- **Parasites' effect on buck small-signal model:** To derive a small-signal model of a voltage mode controlled PWM buck converter which includes the effect of the switching node parasitic capacitance, when a Zero Crossing Detector (ZCD) is present.
  The presence of the switching node parasitic capacitance leads to a change in shape of loop gain as the buck input voltage changes, resulting in different system performances (e.g., load transient response).



Adopted methodologies

- The DF technique and SSA have been exploited to derive the mathematical models of the topologies under analysis, validating the gathered results with SIMPLIS/ELDO simulations.

- A Conducted EMI simulation comparison between the traditional π-Filter and the active filter have been performed, highlighting savings in size and costs retaining the original performances.

Future work

- Find alternative tool for the analysis and description of DC/DC converter, by exploring other mathematical approaches.
  Investigate and propose alternative DC/DC control strategies and networks.

- Improve the active filter architecture (e.g., *adaptive* active filter).

List of external courses

- Modeling and control design of DC/DC converters (Virginia Tech, VA, USA)
- CMOS amplifier frequency compensation (STMicroelectronics)

Submitted and published works

List of attended classes

- 01DPIRO – Advanced Topics in Energy Storage System and Electric Vehicle Drivetrain Design (7/9/2022, 20)
- 01RGBRV – Optimization methods for engineering problems (7/6/2022, 30)
- 02SFURV – Programmazione scientifica avanzata in matlab (21/4/2022, 30)
- 01QRPRV – Satellite Navigation signal exploitation for atmospheric and environmental monitoring (30/6/2022, 15)
- 01DNHRV – System level low power techniques for IoT (15/7/2022, 20)
- 01UNXRV – Thinking out of the box (31/1/2022, 1)
- 01SHMRV – Entrepreneurial Finance (17/2/2022, 5)
- 02LWHRV – Communication (18/9/2022, 5)
- 01UNVRV – Navigating the hiring process: CV, tests, interview (18/9/2022, 2)
- 01UNYRV – Personal branding (18/9/2022, 1)
- 08IXTRV – Project Management (18/9/2022, 5)
- 01RISRV – Public Speaking (18/9/2022, 5)
- 01SYBRV – Research Integrity (18/9/2022, 5)
- 01SWQRV – Responsible research and innovation, the impact on social challenges (18/9/2022, 5)
- 02RHORV – The new Internet Society: entering the black-box of digital innovations (18/9/2022, 6)
- 01SWPRV – Time management (18/9/2022, 2)

Politecnico di Torino

PhD program in

Electrical, Electronics and Communications Engineering