Abstract

This doctoral research extensively explores advanced techniques in the design and control of switching power converters, aiming to address current challenges in the state of the art. These challenges include the impact of approximated (i.e., non-analytical) design on converter characteristics and the inherent issues deriving from the choice of control strategies. A particular focus is also on low-coupling in isolated converters (i.e., Wireless Power Transfer systems) addressing communication and control considerations for compact low-power systems (e.g., biomedical implants). Additional attention is then given to high-frequency optimization challenges related to electromagnetic interference through the use of Spread Spectrum.

This work begins with the design of class-E resonant DC-DC converters, building upon the design methodology proposed by Professors F. Pareschi and G. Setti. Their approach offers a dimensionless and exact solution to the system of differential equations governing the circuit behavior. My contribution involves a twofold improvement: alternative modeling for devices like transformers to enhance flexibility and generality, and a new normalization revealing a 2D design workspace, simplifying conditions representation and facilitating exploration of converter properties.

Building upon refined converter design techniques, a novel dual-frequency control method is developed, overcoming the limitations of on-off control. As in the standard on-off and dual-frequency control, the approach is based on the ability of the converter to alternately operate in a high- and low-power state. The proposed solution has a twofold advantage: on the one hand, soft-switching capabilities are preserved in both operating states; on the other hand, it is possible to eliminate any transient when switching from one state to the other one. The direct consequence is the possibility of increasing the frequency at which the two operating states are switched up to the same order of magnitude as the converter main switching frequency. In this way, the additional ripple introduced by the proposed dual-frequency

control can be decreased to a negligible value. The approach has been validated by measurements on a prototype operating between 4 and 8 MHz in which the control frequency has been tuned up to 500 kHz.

Recent work explores communication capabilities in isolated class-E converters, using low-coupling transformers for high-speed (one bit per clock period) bidirectional data transmission. Reviewed assumptions, considering an increased operating frequency and coreless transformers (i.e., low loss but low coupling factor), improve converter efficiency (92% at 6.78 MHz) at the expense of reduced communication speed (one bit every four clock cycles).

The proposed analytical design advances Wireless Power Transfer (WPT) systems using isolated class-E DC-DC converters. A comparative analysis of class-E-based WPT methodologies is presented. Then, by addressing the challenge of nominal design, this research i) thoroughly reviews the available methodologies for measuring mutual inductance (i.e., the coupling factor); ii) highlights the issues that may arise, and iii) identifies the most suitable technique for a common yet challenging frequency of 6.78 MHz.

In low-power WPT applications, where simplicity and compactness of the system are crucial, a unique primary side control is investigated. It is therefore possible to regulate the power delivered to the load at the desired level by only sensing and modifying quantities available at the primary side. By adding a power regulator at the secondary side, the Desired Operating Point corresponding to the regulator is barely ON (and so dissipating negligible energy) while still providing the correct power to the load is easily detectable at the primary side. The main novelty of the proposed approach is the capability of working without advanced modeling of the system or its parameters estimation. The theoretically developed model is verified by measurements on a 60-mW-class-E-based WPT prototype working at 6.78 MHz and by simulations, only, on state-of-the-art WPT systems, both capacitively and inductively coupled.

The final phase explores Spread Spectrum (SS) capabilities in switching power converters, addressing limited coverage for three-phase circuits. The research demonstrates SS effectiveness in three-phase inverters and tackles high-frequency optimization challenges, specifically, harmonics overlap. Additionally, the study fills a literature gap in Talkative Power Converters, proposing SS guidelines to address EMI issues.