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Investigation of inductive components for power electronics applications

By

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Declaration

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Investigation of inductive components for power electronics applications

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The demand for high power density and highly efficient power electronics converters is increasingly pushing the optimisation of inductive components. Starting from state of the art in inductor design, this thesis proposes some newly developed considerations and concepts in the design of inductive components for power electronics applications, with a particular focus on inductors operating in DC-DC converters. The addressed challenges regard the core saturation, which is the principal limit to design optimisation, and the core loss modelling, which is extremely critical due to the biasing effect of the DC current. The problem of the optimised design of inductors for DC-DC converters also faces the high-frequency operation of the windings, which can strongly influence the total losses of the device.

The design analysis of an output inductor for a buck converter is presented. The modelling of inductors for DC-DC converters is discussed, and some considerations are proposed on the most suitable approaches depending on the specific design requirements. In addition, the critical aspects of the multi-objective design are discussed, focusing on the long computational time required. The multi-objective optimisation is approached with an artificial immune system based algorithm and enhanced with the adoption of a classifier system for the constraint evaluation. A classification system is proposed to evaluate the constraint of the configurations examined in the multi-objective optimisation process, highlighting interesting results in reducing the number of the required time-consuming computational tasks.

While some applications require a custom design of magnetic components, power electronic devices destined for mass production generally require commercially available components. In this case, the goals of high power density and high efficiency are reached by appropriately selecting the optimised part in the manufacturer catalogues. The conventional sizing approach of inductors for DC-DC converters aims to ensure the operation of the device in linear and stable conditions, overestimating the required inductance value and thus selecting an oversized magnetic component. It is well known that the operation of inductors in partial saturation reduces the size of an inductor for a given inductance value, increasing the power density of a

DC-DC converter. However, inductors operating in partial saturation require appropriate modelling that considers the non-linearity introduced by magnetic material behaviour. To this end, a method for the experimental identification of the differential inductance profile of commercial ferrite inductors is presented, also considering the effect of the overheating caused by the operative power losses. The experimental setup and the identification procedure to perform the characterisation are discussed. In addition, the modelling of the differential inductance profile is evaluated for the fast simulation of the current and voltage waveforms when the inductor operates in non-linear conditions.

The proper modelling of magnetic device properties can also be used to implement interesting control strategies for different energy conversion devices. In particular, this thesis evaluates the effectiveness of magnetic control for resonant converters, focusing on Wireless Power Transfer systems. The proposed magnetic control strategy is implemented through a controlled variable inductor. The design and modelling of a controlled variable inductor are described, and a prototype is realised and tested in an experimental Inductive Wireless Power Transfer system to verify the effectiveness of the magnetic control strategy. The regulation and supply system of the inductance value is also analysed. In conclusion, a controlled variable inductor is proposed for the regulation of a Capacitive Wireless Power Transfer system.