Multi-objective Optimization of Buck Converters Using Genetic Algorithms

Kang Minsung[1], Koichi Shigematsu[2], Jun Imaoka[2], Masayoshi Yamamoto[2]
[1]Nagoya University
[2]Institute of Materials and Systems for Sustainability, Nagoya University
kang.minsung.p3@s.mail.nagoya-u.ac.jp

Introduction

With the continuous demand for higher efficiency and miniaturization in electronic devices, the optimal design of power converters has become critically important. Buck converters, which are fundamental for stepping down DC voltage, pose a classic design challenge involving a trade-off between their physical volume and power loss. Conventional design methods often require numerous prototypes and evaluations, leading to increased development costs and longer time-to-market. This study aims to propose a design method that optimizes the trade-off between total loss and inductor volume of a buck converter by applying a genetic algorithm (GA) for the multi-objective optimization of MOSFET selection and inductor design parameters.[1]

Optimization Methodology and Design

The optimization considers both discrete variables, such as MOSFET selection from more than 1,300 candidates, and continuous variables, including inductor dimensions, winding number, and switching frequency. This wide and heterogeneous design space makes the optimization process complex. To address this, an integrated workflow was developed that combines a genetic algorithm (GA) with LTspice circuit simulations. The GA is particularly suitable for this purpose, as it can efficiently handle multi-objective problems with mixed variable types.

A high-fidelity loss model was implemented to ensure accurate evaluation of candidate solutions. MOSFET switching losses (E_{on}, E_{off}) were pre-characterized using double pulse test (DPT) simulations, while conduction losses were derived from theoretical equations. For the inductor, both copper loss and core loss were considered, the latter calculated using the Improved Generalized Steinmetz Equation (iGSE)[2], which reliably estimates losses under non-sinusoidal waveforms. Practical design constraints, including ripple current limits, MOSFET voltage ratings, and magnetic saturation of the core, were also imposed to ensure feasible solutions.

Through this framework, the GA iteratively generated and evaluated design candidates, converging toward a set of non-dominated solutions, referred to as the Pareto front.

Summary

The proposed approach was successfully applied to the multi-objective optimization of a buck converter, yielding a Pareto front that illustrates the trade-offs between efficiency and compactness. Importantly, the analysis identified a practical design "sweet spot," with balanced solutions concentrated in the 100–400 kHz switching frequency range and inductance values below 400 μH. These insights provide practical guidelines that support efficient decision-making in the early stages of converter design.

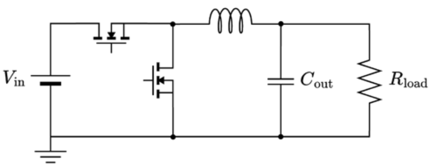

Fig. 1. Buck converter circuit

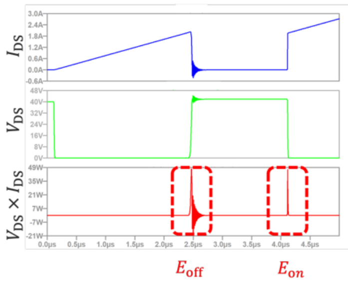

Fig. 2. DPT waveforms for MOSFET switching loss

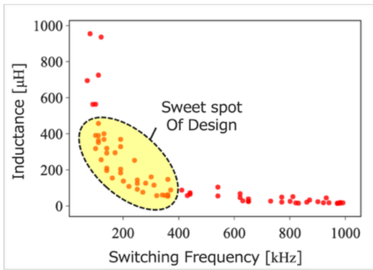

Fig. 3. Optimization results: design sweet spot

References

[1] B. Zhou et al., "Multi-objectives optimization of parameter design for LLC converter based on data-driven surrogate model," IET Power. Electron. (2023)

[2] J. Mühlethaler et al., "Improved core-loss calculation for magnetic components employed in power electronic systems," IEEE Trans. Power Electron. (2012)