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Original article

Design and optimization of buck and double buck converters by means of geometric programming

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Abstract

This paper describes a new method for determining the optimal components values and switching frequencies of buck DC–DC converters. First, we revisit some concepts of the optimization technique named geometric programming. Then, we observe that the problem of converter designing can be modeled by means of an objective function and certain constraints which can be written in a specific form known as the posynomial form. The constraints involve expressions that depend on magnitudes such as efficiency, bandwidth, and current and voltage ripples.

Specifically, we apply the design method in a synchronous buck converter and a synchronous cascade buck converter. This technique can efficiently determine the optimal sizing of the converter or the infeasibility of the set of design constraints in a quickly manner and, therefore, it can eases the cumbersome task of manually designing buck DC–DC converters.

As an additional result, we conclude that optimal design of the synchronous cascade buck converter performs more efficiently than the optimal design of the synchronous buck converter, given certain realistic set of specifications for wide-range voltage conversion.

Keywords: Synchronous buck converter; Synchronous cascade buckconverter; Geometric programming; Optimization; Switchingconverter design

1. Introduction

Many designers have noted that properly designing DC–DC converters is a time-consuming and costly process. Consequently, there is considerable interest in applying optimization methods to ease the burden of such a task. This paper introduces a new method to determine the optimal parameter values in a DC–DC converter design. The method, which is based on geometric programming (GP), allows designers to deal with a wide range of specifications and constraints, and is extremely fast. Moreover, the method either results in a globally optimal solution or conclusively determines infeasibility.

In recent years, the performance of buck DC–DC converters has improved. Some of the advances are related to energy-storing elements, which are now smaller and have fewer losses. Switches have also improved in that they are now faster, and have a smaller on-state resistance and a better blocking voltage. However, converter design parameters still have to be optimized to comply with dimension constraints and improve their efficiency.

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Several authors have reported different methods to optimize the converter designing process. The process takes into account certain objective functions and constraints which are nonlinear, therefore linear programming methods are not suited for this task.

It is worth noting that the following papers report several of recently published approaches for optimizing DC–DC power conversion design.

Specifically, optimization of parameters such as current ripple, switching frequency and voltage swing in the MOSFET gate driver is reported in [9] to obtain an optimal design for monolithic DC–DC buck converters. Also Refs. [20,13] present procedures to minimize magnitudes such as efficiency or the electromagnetic interference (EMI).

Nevertheless, the methods in [9–13] optimize only one parameter or the optimization procedure is divided into several stages and then only one or two parameters are selected at each stage. Consequently, these procedures do not allow that a great number of constraints be imposed simultaneously.

In order to take into account simultaneously a great number of constraints, some authors have reported nonlinear programming methods for designing DC–DC converters. Important related studies are those of Seeman and Sanders [16], who optimized a switched-capacitor converter design by means of Lagrangian functions, and those of Balachandran, Wu et al. [1,17] which describe the optimization of DC–DC converters by means of augmented Lagrangian. Other nonlinear programming methods such as the sequential quadratic programming method have also been used for designing of DC–DC converters. For example, Busquets-Monge et al. [3] designed of a boost power-factor-corrector converter using this method.

Nevertheless, the methods in [16,3] only ensure to achieve a local optimum, therefore the solution depend on the starting point.

Unlike the previous references, this paper presents a new method for designing DC–DC converters which optimizes a nonlinear objective function under nonlinear constraints and the solution does not depend on the starting point. Both the objective function and the constraints are expressed in a particular form which is known as the posynomial form and is explained in Section 2. An optimization problem expressed in posynomial form is called a geometric program. Geometric programs can be solved by means of efficient interior-point algorithms. The main advantage of this procedure is that, despite dealing with nonlinear objectives and constraints, it gives the global optimum or indicates infeasibility very quickly.

Researchers in optimization methods have been interesting in geometric programming (GP) since the 1960s [2,6]. However, the real advantages of this technique are only starting to be appreciated. The reason for this is the significant development of interior point methods for solving convex optimization problems in the last fifteen years [12]. GP solution methods are now extremely efficient and reliable.

The method that this paper has adapted to buck DC–DC converter design, has been successfully applied in several engineering fields such as transistor sizing [15], filter design [11], phase locked loop (PLL) circuit design [4], industrial manufacturing [10], among others.

The present paper revisits the basics of geometric programming and then analyzes the converter efficiency and usual design constraints for two common buck converter topologies. Specifically, it applies the proposed procedure based on geometric programming to a synchronous buck converter and a synchronous cascade buck converter. The advantages of the proposed method are particularly important in the design of synchronous cascade buck converter where we select a large number of components under a great variety of simultaneous constraints.

A cascade topology is best suited when we need broad voltage conversion ratios, because the cascade topology is less demanding in terms of switch turn-on time. Despite this, it would seem that as far as the efficiency is concerned, a single-stage converter is usually a better choice than a two-stage converter. Nonetheless, the present paper shows that the cascade stage is slightly more efficient given the realistic specifications imposed. As an example, we impose low ripple constraints to prevent fast-scale nonlinear behaviors and EMI in such converters [21]. It is worth to note that the proposed design method is focused on steady-state performances and the buck and double buck converter still would require of a suitable controller [19] to fulfill with certain dynamical performances.

Thus, the modeling of design expressions in such a manner that GP method can be applied to optimize buck and cascade buck converters constitutes the main contribution of this paper. To our knowledge, no previous design approach in converters that need to determine a great number of parameters had taken into account the convexity of the optimization problem. The previous approaches only ensure to achieve a local optimum, whereas the proposed procedure ensures the global optimum achievement. It is of maximal interest that the design procedure reaches the optimum, thus providing not only a good solution but the best solution.