Comments and Corrections

Comments on "Design and Analysis of Switched-Capacitor-Based Step-Up Resonant Converters"

Adrian Ioinovici, Chi K. Tse, and Henry Shu-Hung Chung

***Abstract*—With reference to a recently published paper, the realization of line and load regulation in switched-capacitor-based converters is discussed. We point out that achieving zero-current switching at the expense of losing line and load regulation is not practically feasible.**

In [1], a way of realizing zero-current-switching (ZCS) in step-up switched-capacitor (SC) converters has been presented. The idea is based on the authors' earlier proposal of the so-called "switched-capacitor resonant converters" which achieve soft switching by inserting small inductors in series with the switching capacitors. The fundamental problems associated with the so-called "switched-capacitor resonant converters" has been discussed in a recent publication [2]. The most severe limitation is the inability to provide regulation against input voltage changes and transient load changes. In this comment, we wish to comment on the technical feasibility of the specific circuits reported in [1].

First of all, it should be pointed out that voltage regulation is an important requirement for all kinds of power converters. The proposed circuits by [1] provide fixed voltage ratios. This implies that the output voltage will follow any change in the input voltage and that no satisfactory transient response can be guaranteed in case of load variation. The converter thus fails to meet the main requirement of any switching power supply, which is to provide a constant output voltage against line and load variations. Closed-loop control is mandatory for achieving satisfactory load transient responses as well as line regulation. Therefore, the basic argument presented in [1, Sect. 6] that their converters require no closed-loop control because they have fixed voltage ratios is clearly not correct.

As should be widely known, prior developments of SC power supplies have already advanced to a point where full output voltage regulation has been achieved in a versatile manner [3]–[10]. Reference [1] however, has been devoted to the historical case of open-loop SC circuits where switching capacitors are fully charged in each intermediate step, thus providing no output regulation. The basic problem of losing voltage regulation in such historical SC converter circuits has been discussed in [2] in terms of partial and full charging of the switching capacitors. The key idea is that the capacitors should never be fully charged at the nominal duty cycle in order to allow the converter to "maneuver" over an adequate range of voltage ratio in case of line voltage changes and load transients. In other words, the duty cycle is continuously adjusted via feedback to achieve a tight output voltage regulation.

Moreover, the circuits proposed in [1] have illuminated another interesting design problem which may further affect the ability to regulate even if a closed-loop control is reinstated in such circuits. As shown in the detailed circuit analysis in [1], almost the entire half switching period has been occupied by the resonating waveform so as to minimize the current amplitude (thus raising efficiency), as shown in [1, Fig. 7]. Since ZCS requires the turn-off instant to be located after the resonating current waveform reaches zero and before the end of the half switching period, there is very little room for varying the switching instants other than those defined by the operating point. This transpires a practical design tradeoff between the amplitude of the current spike, the assurance of ZCS conditions and the amount of the control headroom available. Thus, the suggested design choice given in [1] (i.e., the resonating period equals 90% of the switching period) has clearly omitted this consideration.

In conclusion, the development of SC power supplies has gone through several stages of advancements, beginning from the conventional voltage multipliers and charge-pump circuits, to fully-regulated voltage step-up and step-down converters, and eventually to integrable SC power supplies. As the field continues to advance, we believe it is important to clear up misconceptions so that research efforts will not be wasted in re-investigating problems for which sophisticated and somewhat mature solutions are already available from prior developments.

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A. Ioinovici is with the Department of Electrical and Electronic Engineering, Holon Academic Institute of Technology, Holon 58102, Israel (e-mail: adrian@hait.ac.il).

C. K. Tse is with the Department of Electronic and Information Engineering, Hong Kong Polytechnic University, Hong Kong (e-mail: cktse@ieee.org).

H. S.-H. Chung is with the Department of Electronic Engineering, City University of Hong Kong, Hong Kong.

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