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Research Article

A New High Step-Up Soft-Switched DC-DC Converter, Consisting of Resonant Switched Capacitor and Conventional Boost Converters

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Extended Abstract:

The escalating demand for high-efficiency, high-voltage-gain DC-DC power conversion in renewable energy systems—particularly in photovoltaic (PV) applications where a low-voltage DC source (e.g., 20–40 V from a solar panel) must be interfaced with a high-voltage DC bus (e.g., 380–400 V for a grid-tied inverter)—has driven significant research into advanced converter topologies. Conventional step-up converters, such as the basic Boost converter, are fundamentally limited in their voltage gain, especially at practical duty cycles below 0.8, due to severe parasitic effects, high switch voltage stress, and hard-switching losses. While numerous high step-up topologies have been proposed—including those based on coupled inductors, voltage multipliers, and switched-capacitor (SC) networks—each comes with its own set of trade-offs, such as high component count, complex control, circulating currents, or excessive voltage/current stress on semiconductors.

This paper proposes a novel, high-performance DC-DC converter topology that synergistically integrates the best attributes of two distinct approaches: the resonant switched-capacitor (RSC) converter and the classical Boost converter. The core innovation of the proposed structure is its ability to achieve a very high voltage gain while ensuring soft-switching operation for all active switches, significantly reduced voltage stress on power semiconductors, and continuous input and output currents—all with a moderate component count and a simple, two-switch control scheme.

The proposed converter's architecture is elegantly constructed by cascading a modified version of a resonant switched-capacitor cell with a conventional Boost stage. The SC cell comprises two symmetrical branches, each containing a pair of diodes and capacitors (D1a/C1a/D2a/C2a and D1b/C1b/D2b/C2b), which are driven by a dedicated control signal. This is coupled with a resonant inductor (Lr) that facilitates soft switching. The Boost stage is formed by an additional inductor (LBoost), a capacitor (CBoost), and a second active switch (SBoost), which is controlled independently. The overall structure is designed so that the voltage gain is a multiplicative function of both the duty cycle of the Boost switch and the number of SC cells, offering two degrees of freedom for gain optimization.

A critical contribution of this work is the comprehensive analysis of the converter's six operational modes over a complete switching cycle. This detailed state-by-state analysis rigorously demonstrates that both power switches, S1 and SBoost, achieve Zero Voltage Switching (ZVS) turn-on and Zero Current Switching (ZCS) turn-on/turn-off. This is accomplished through the resonant interaction between Lr and the SC network, which ensures that the current through the body diode of each MOSFET is positive just before the switch is turned on, thereby clamping its voltage to near zero. This soft-switching capability is paramount, as it virtually eliminates the dominant switching losses that plague

hard-switched high-gain converters, leading to a substantial improvement in overall efficiency, especially at high switching frequencies.

Furthermore, the paper provides a thorough derivation of the converter's voltage gain and voltage stress on its components. For a converter with n SC cells, the theoretical voltage gain is derived as $G = (1 + 2n) / (1 - D)$, where D is the duty cycle of the Boost switch. This multiplicative gain mechanism means that a very high gain can be achieved without pushing the duty cycle to impractical levels (e.g., 0.9+), where the Boost converter's performance degrades significantly. For instance, to achieve a gain of 13 (a typical requirement for a PV application with a 30 V input and 390 V output), the proposed converter can operate at a moderate duty cycle of 0.75 with just two SC cells, whereas a conventional Boost converter would require a duty cycle of approximately 0.923, which is infeasible in practice due to control instability and excessive losses.

Equally important, the analysis of voltage stress reveals that the maximum voltage across any switch or diode is only $Vout / (1 + 2n)$. In the two-cell example, this stress is limited to one-fifth of the output voltage, which is a dramatic reduction compared to the full output voltage stress experienced by the switch in a standard Boost converter. This allows for the use of lower-voltage, lower-Rds(on) MOSFETs and faster-recovery diodes, which inherently have lower conduction and switching losses, further boosting the system's efficiency and power density.

To validate the theoretical claims, a 200-W, 380-V output prototype of the proposed converter was designed and simulated in PSpice. The simulation results are in excellent agreement with the analytical predictions. Key waveforms confirm the soft-switching operation: the turn-on of both S1 and SBoost occurs at near-zero voltage, as the current commutates from their respective body diodes. The currents through the diodes (D1a/b and D2a/b) are shown to naturally fall to zero before the diodes turn off, thereby eliminating the reverse recovery problem, a major source of loss and EMI in high-frequency converters. The continuous nature of both input and output currents is also confirmed, which is beneficial for reducing input filter size and minimizing output voltage ripple.

A comparative analysis with other state-of-the-art high step-up converters highlights the proposed topology's superior balance of features. Unlike many coupled-inductor-based solutions, it has a common ground between input and output, simplifying EMI filter design and system integration. In contrast to pure SC converters, it offers continuous input current and a controllable gain via duty cycle, making it robust to input voltage and load variations. The component count is also shown to be competitive, with a total of 2 switches, 4 diodes, 5 capacitors, and only one magnetic core (a significant advantage over multi-winding coupled inductors).

In conclusion, this paper presents a highly effective and practical solution for high step-up DC-DC conversion. By ingeniously merging resonant switched-capacitor and Boost technologies, the proposed converter successfully overcomes the key limitations of its predecessors: it achieves a very high voltage gain, ensures soft-switching for all active devices, drastically reduces semiconductor voltage stress, provides continuous input and output currents, and eliminates diode reverse recovery losses. These combined advantages translate directly into a converter with higher efficiency, greater reliability, improved power density, and better suitability for real-world renewable energy applications. The work represents a significant step forward in the design of next-generation, high-performance power electronic interfaces.

Keywords: High Step-Up Converters, Resonant Switched-Capacitor Converters, Switched-Capacitor Converters, Zero Voltage Switching and Zero Current Switching.

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