Electric Power Systems Research 119 (2015) 83–90

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

DC-DC multiplier boost converter with resonant switching

Julio Cesar Rosas-Caro [a], Jonathan Carlos Mayo-Maldonado [b], Antonio Valderrabano-Gonzalez [a,*], Francisco Beltran-Carbajal [c], Juan Manuel Ramirez-Arredondo [d], Juan Ramon Rodriguez-Rodriguez [e]

[a] Universidad Panamericana Campus Guadalajara, Prol. Calzada Circunvalacion Pte. No. 49, Col. Ciudad Granja, Zapopan, Jal, 45010, Mexico
[b] University of Southampton, CSPC group, Faculty of Physical and Applied Sciences, SO17 1BJ, Southampton, United Kingdom
[c] Universidad Autonoma Metropolitana, Unidad Azcapotzalco, Av. San Pablo No. 180, Col. Reynosa Tamaulipas, C.P. 02200 México, D.F., Mexico
[d] CINVESTAV Unidad Guadalajara, Departamento de Sistemas de Av. del Bosque 1145, Colonia el Bajio, Zapopan, Jal, 45019, Mexico
[e] Instituto Tecnologico de Morelia, Av. Tecnologico No. 1500 C.P. 58120 Morelia, Michoacan, Mexico

ARTICLE INFO

Article history:
Received 25 February 2014
Received in revised form 14 August 2014
Accepted 3 September 2014
Available online 26 September 2014

Keywords:
DC-DC power converters
Power electronics
Converters
Low power electronics
Switched capacitor circuits

ABSTRACT

This paper proposes an improved Multilevel Boost Converter, also known as Multiplier Boost Converter, in which the spike-type current among capacitors is eliminated through one resonant inductor, achieving some resonant-type current waveforms. Experimental results demonstrate the applicability of the proposition.

1. Introduction

There are many practical applications where a Switching Mode Power Supply (SMPS) requires wide conversion ratios such as laser, X-ray systems, automotive, telecommunication, ion pumps, uninterruptible power supplies UPS, industrial systems, electrostatic systems, battery-powered portable devices, and renewable energy conversion systems [1–4]. For instance, PV panels and fuel cells generate a low amplitude dc-voltage that needs to be boosted to some hundred volts to feed grid-tie inverters. In telecom standard equipment, in order to provide Internet services, the 48 V of the DC battery set has to be boosted to a 380-V intermediate DC bus, etc.

Conventional transformerless topologies are not suitable to effectively perform the mentioned tasks, so that transformer or coupled-inductor-based topologies are commonly used [5,6]. However, it is also known that there exist several disadvantages with respect to the use of transformers such as: size, weight and frequency limitation for the resultant topologies. For this reason, there exists an increasing interest in the development of novel transformerless topologies that can perform efficiently through a wide conversion ratio [1–3,7–13].

In order to step-up or-down the voltage, several topologies have been proposed based on Switched Capacitor (SC) circuits that do not include transformers, providing high efficiency [3,7–13]. These topologies offer a state of the art solution, combining conventional converters with either switched capacitors voltage multipliers or dividers, depending on the converter's step-up or step-down mode, respectively.

For the stepping-up case, some propositions indicate that the combination of one conventional converter with a diode-capacitor voltage multiplier achieves a voltage gain that would be impractical for that converter [1–4,14–20].

Particularly, the multilevel boost converter [2], also known as multiplier boost converter, Fig. 1(a), combines the boost converter with the Cockcroft-Walton Voltage Multiplier for controlling the output voltage by pulse width modulation (PWM), achieving a high voltage gain because the diode-capacitor voltage multiplier.

There are different ways for implementing the voltage multiplier stage; Fig. 1 shows three of them. The advantage of the topology in Fig. 1(a) is that all capacitors hold the same voltage,

* Corresponding author. Tel.: +52 33 1368 2200; Fax: +52 33 1368 2201.
E-mail addresses: rosascarojc@hotmail.com (J.C. Rosas-Caro), jcmm1g11@ecs.soton.ac.uk (J.C. Mayo-Maldonado), avalder@up.edu.mx, Antonio.Valderrabano@inbox.com (A. Valderrabano-Gonzalez), fbeltran@azc.uam.mx (F. Beltran-Carbajal), avalder@up.edu.mx (J.M. Ramirez-Arredondo), jramirez@gdl.cinvestav.mx (J.R. Rodriguez-Rodriguez).

http://dx.doi.org/10.1016/j.epsr.2014.09.003
0378-7796/

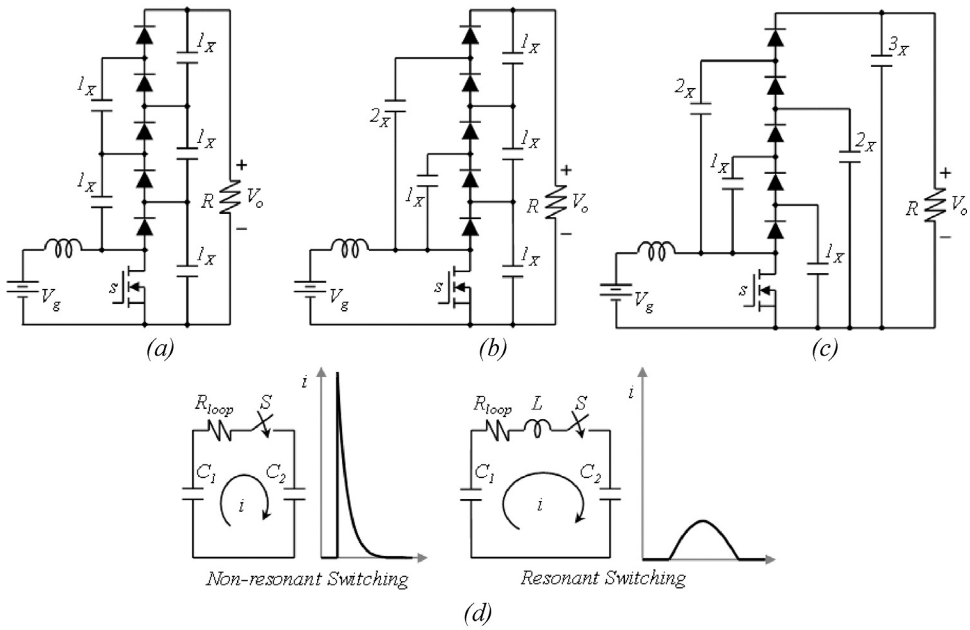

Fig. 1. (a), (b) and (c) Multiplier boost converters, (d) current among capacitors depending on the switching behavior.

which is relatively low. On the other hand, in Fig. 1(b), capacitor 2_X holds twice of the voltage on the others. However, it has been shown in [15] that by separated capacitors in the voltage multiplier, Fig. 1(b), the converter attains better performance.

A similar analysis may be applied to the capacitor bank on the right side, which would lead to the scheme depicted in Fig. 1(c). Such circuit does not have been reported in the open research. It represents the starting point of the proposed topology. The capacitors' labels indicate the voltage across them, assuming 1_X the voltage of a boost converter.

Diode-capacitor voltage multipliers are unidirectional Switched Capacitor (SC) converters operated in full charge interchange [7]. Their primary drawback is the current waveform among capacitors (through diodes), which are spike-shape [2–4,7,14,15,18,20], Fig. 1(d). The current in this case is limited only by the parasitic resistance in the loop. A major disadvantage of currents with spikes is that such condition force overrating in the components. This leads to a sub-utilization of the installed devices because switching devices are not designed to drain an average current that is much smaller than their peak current. Moreover, conduction losses in MOSFETS and capacitors are proportional to the RMS current, and then, the spikes lead to higher conduction losses on those components, even for low average currents. This situation worsens using devices with smaller parasitic resistance.

Resonant switching has proved to overcome this issue with a reasonable size and cost in topologies combining conventional converters with diode-capacitor voltage multipliers [21]. Fig. 1(d) illustrates the current between two capacitors in both the non-resonant and resonant switching, for the same charge interchange (same area under the current waveforms). The non-resonant switching reaches a larger peak current. The peak increases if the parasitic resistance decreases. It is expected that new devices will get lower parasitic resistance increasing this issue, which increases the EMC difficulties [22]. The current in the resonant switching branch exhibits a lower maximum peak. For this reason, it is highly desirable to achieve resonant switching in the diode-capacitor voltage multiplier.

This paper proposes an improved version of the multiplier boost converters based on resonant switching. Moreover, the principle may be extended to other hybrid converters, which use voltage multipliers. The proposed converter achieves a high voltage gain without the use of extreme duty cycles or transformers. The main characteristics become: (i) every switching device blocks a similar voltage; (ii) the input current is naturally continuous while the converter includes only one inductor for energy storage.

The paper is organized as follows. Section 1 provides the state of the art, motivation and introduction. Section 2 exposes the proposed topology and simulation waveforms to explain the theoretical analysis. Section 3 presents design guidelines with an easy and innovative point of view. Experimental results validate the approach in Section 4, and the conclusions of Section 5 close the paper.

2. Proposed topology

The main objective of the topology design is to implement resonant switching in the diode-capacitor voltage-multiplier for improving the operation.

Adding an inductor for resonant switching somewhere in the circuit, would cause a resonant-type waveform in a couple of capacitors while the rest of them will still present spikes. To connect a small resonant inductor in series with each capacitor becomes undesirable since the number of components would increase, moreover the output impedance would also be degraded if an inductor is in series with the output capacitor.

In the proposed topology only one resonant inductor is necessary in order to shape the current for all the switching devices, making it resonant when the inductor is connected as in Fig. 2(a). This situation is possible since this is the only point (apart from the ground) for draining the current among capacitors during both switching stages. Diodes in Fig. 2 are termed s_2 to s_6, to avoid confusions with the duty cycle.

2.1. Boost converter stage

Assuming small ripple and continuous conduction mode [29] for the energy storage inductor L, its average voltage becomes,

$$L\frac{d\left\langle i_L\right\rangle}{dt} = \langle v_L\rangle = V_g - (1-d)\langle v_1\rangle \tag{1}$$