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A novel low-ripple interleaved buck–boost converter with high efficiency and low oscillation for fuel-cell applications

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ABSTRACT

Efficiency and dynamics of DC–DC converters play a major role in proficiency of renewable energy exploitation. This paper presents a novel DC–DC interleaved buck–boost converter for fuel-cell applications. While keeping the same step-up/step-down voltage transfer ratio, the proposed converter exhibits non-pulsating I/O currents using interleave technique. A damping network is also added to improve the inner dynamics of converter. Besides the steady state operation based on state space averaging (SSA) method, design considerations of converter are thoroughly elaborated. MATLAB/SIMULINK environment is used for simulating the steady state operation of proposed converter, and the experimental results are presented, to verify the theoretical expected merits of the converter including high efficiency, non-pulsating I/O currents and low voltage oscillation. Prototype setup of 360 W and 36 V output voltage for a fuel cell with a brand of “FCgen 1020ACS” Ballard Power Systems, Inc was implemented. Experimental results including efficiency and time domain responses in the steady state show impressive benefits of the proposed converter.

Introduction

With ever-increasing use of DC–DC power converters in many applications such as battery charging, fuel cell systems, power factor correction (PFC), hybrid electric vehicles, communication power supply, maximum power point tracking (MPPT) of photo voltaic system (PVs) and for other renewable sources’ maximum energy extraction, a considerable number of studies have been conducted over these kinds of converters. On the whole DC–DC converters fall into three categories; buck, boost and buck–boost. A buck–boost converter is required when the output voltage is within the input voltage range [1–12].

Although there are many single-active-switch step-up/step-down DC–DC converters such as Sepic, Cuk, and conventional inverting buck–boost and flyback converters, the non-inverting buck–boost one constructed by combining a boost and a buck circuit in cascade with two independently controllable switches is a popular choice for such applications requiring bidirectional conversion capability, high efficiency and low component stresses [2–4].

In addition to the above-mentioned step-up/step-down DC–DC converters topologies, it is possible to combine a buck converter with a boost one in cascade leading to a single inductor high performance buck–boost converter for low voltage applications [5–7].

Although other topologies, capable of working through high voltage applications, are reported in [8,9], their controlling systems are completely involved. Another topology is KY buck–boost converter with improving controlling system via eliminating right-half-plane (RHP) zero in continuous conduction mode (CCM) [10],but it poses a major problem in four power switches which results in increasing the cost of the device. In order to mitigate this problem, new topology with two reduced active switches and aforementioned advantage is reported in [11].

Most of the DC–DC converters mentioned earlier have the drawback of pulsating input/output (I/O) currents resulting in a high noise level and complicated controlling system as well as current limitations. In many applications, especially in hybrid electric vehicles, power factor correction and fuel cell, low-ripple current is preferred [13–15]. For subsiding this problem the two-switch tri-state buck–boost is proposed [16] and with regard to capability of using large inductance in pseudo-continuous conduction mode (PCCM) [17,18], lower-ripple I/O currents can be achieved. Another possible solution for this problem is to use the interleaved technique. Using this technique further benefits like harmonic cancellation, better efficiency, component stresses reduction, better thermal performance, and high power density can be easily obtained [13,15,19–22]. The concept of interleaving is not new

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Nomenclature

C_1, C_2, C_d	input, interface and output capacitor
D_{12}	steady state duty cycle of boost stage
D_{34}	steady state duty cycle of buck stage
$d_{12}(t)$	duty cycle of boost stage
$d_{34}(t)$	duty cycle of buck stage
$i_{L1}–i_{L4}$	inductor 1 through inductor 4 current
$M(u)$	converter voltage transfer ratio
$M(D_{12}, D_{34})$	converter voltage transfer ratio
P_{Rd}	power dissipation in damping network resistor
$S_1–S_4$	$Q_1–Q_4$ Signal activations
T_s	switching period
u	unified controlling variable
v_{C1}, i_{C1}	capacitor 1 voltage and current
v_{C2}, i_{C2}	capacitor 2 voltage and current
v_{Cd}, i_{Cd}	damping network capacitor voltage and current
v_g, i_g	input voltage and current
$v_{L1}–v_{L4}$	inductor 1 through inductor 4 voltage
v_{out}, i_{out}	output voltage and current

and covers a wide area of applications [22]. In [13], the 16-phase interleaved bidirectional boost converter for hybrid energy storage system (HESS) has solved I/O currents high ripple but this topology can just operate in the boost mode and it is not generalized in both buck and boost operating modes [15]. Proposes an interleaved non inverting buck–boost converter with a low-output current ripple, but in this topology counteracting the input voltage variation in wide range is not completely achieved. In [20], the double-switch

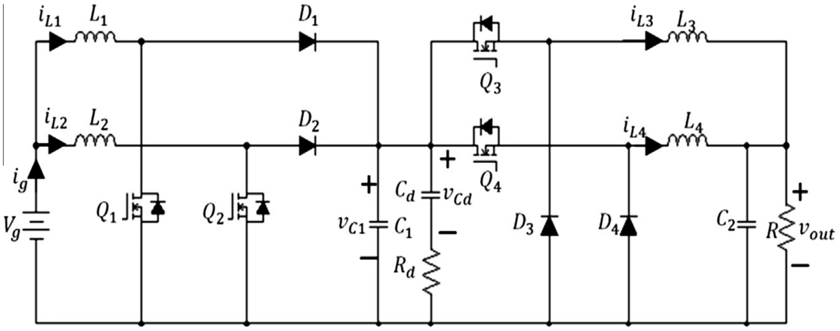

Fig. 1. Schematic circuit diagram of proposed converter.

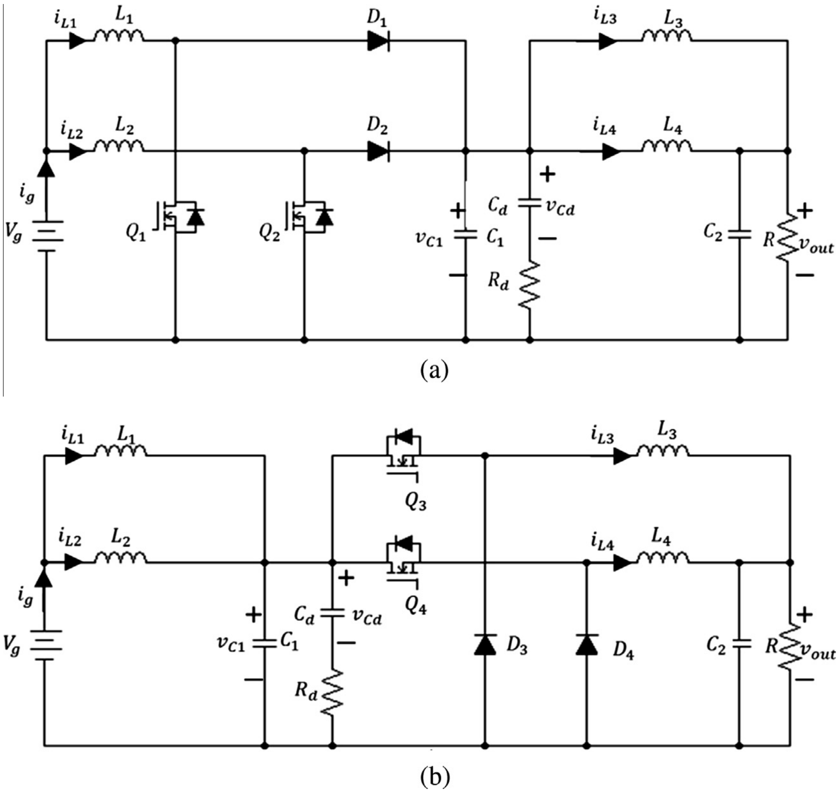

Fig. 2. Operating modes of proposed converter: (a) boost mode; (b) buck mode.