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A New High Step-Down DC-DC Converter for Renewable Energy System Applications

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Abstract

This paper proposes a new topology of a high step-down dc-dc converter with a conversion ratio of approximately 20 times for high-input and low-output voltage applications such as renewable system applications. This proposed converter employs only one single switch with low control complexity. In this paper, the converter configuration is presented and its operating principle under continuous conduction mode (CCM) is described. The relationship between the step-down voltage ratio and the duty cycle is also presented in order to illustrate the performance of the proposed converter. In addition, the laboratory phototype of the proposed converter is implemented. The simulation and experimental results are shown to demonstrate the effectiveness of the proposed high step-down single-switch dc-dc converter.

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Keywords: DC-DC converter; High step-down conversion ratio; Renewable energy; Single switch

1. Introduction

Due to the energy shortage and the environmental problems, the renewable energy sources, such as photovoltaic (PV) arrays and wind turbine generators, have received increasingly attentions [1]. The electric power generated from these renewable energy sources can be connected to the grid through the proper power converters. In addition, the stand-alone power system based on renewable energy and storage devices is an alternative solution to provide

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electricity for the remote areas [2]. The stand-alone renewable energy system typically requires the battery for energy storage to supply the load power when the renewable energy sources are not available due to the climatic operating conditions [3]. For storing energy in the battery the conventional buck converter is commonly used because of its simple structure and low control complexity. The battery output voltage is lower than the input voltage generated from such renewable energy sources. However, for the high-input and low-output voltage systems the conventional buck converter needs to operate under the extreme duty cycle to achieve the desired output voltage with high step-down voltage conversion ratio. Consequently, the active power device suffers from the voltage and current stress and the power loss of the buck converter increases significantly. As a result, the converter efficiency is deteriorated.

To overcome the limitation of the conventional buck converter for the high-input and low-output voltage applications, several step-down dc-dc converter topologies have been proposed to achieve the high step-down voltage conversion ratio. The n-stage cascaded buck converter configurations are employed to obtain the higher voltage gains compared with the conventional buck converter. However, the use of the n-stage buck converter needs more active power switches and components including the more gate drive circuits, which not only increase the cost and the power losses of the converter but also decrease the efficiency [4]. In addition, the coupled inductor is introduced to the step-down dc-dc converter to provide a high voltage conversion ratio. Unfortunately, the energy stored in the leakage inductor of the coupled inductor causes high voltage spikes on the power switches, thereby reducing the corresponding efficiency [5]. The isolated step-down dc-dc converter with a transformer can provide the high voltage-conversion ratio by properly adjusting the turn ratio of the isolated transformer [6]. However, the converter efficiency is relatively low because of its voltage stress and leakage inductance energy. In addition, the cost and the size of the converter increase due to the added transformer.

In this paper the high step-down single-switch dc-dc converter is proposed for high-input and low-output voltage applications such as renewable energy systems. The proposed converter provides a much higher step-down voltage conversion ratio compared with the conventional buck converter without adopting the extremely short duty cycle. The proposed converter topology is presented in the next section. The operating principle of the proposed converter under the continuous conduction mode is described. A 100-W prototype of the proposed converter was implemented. Simulation and experimental results are shown in order to illustrate the effectiveness of the proposed converter.

2. High Step-Down DC-DC Converter Topology

The proposed high step-down dc-dc converter configuration is shown in Fig. 1. This proposed topology uses only one active power switch to increase the step-down conversion ratio without employing an extremely low duty cycle. As can be seen in Fig. 1, the proposed converter consists of two capacitors, three inductors and four diodes. The proposed converter topology can be derived from the combination of a cascaded quadratic buck converter and a diode-assisted buck converter. By integrating both converters, the high step-down conversion ratio can be achieved.

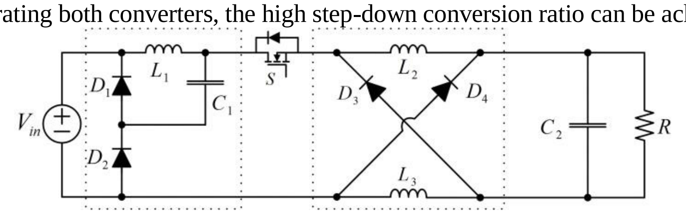

Fig.1: The proposed high step-down dc-dc converter configuration

There is only one power switch located in the proposed converter topology. Therefore, the operating principle of the proposed converter can be basically classified into two operation modes; switch S is turned on and switch S is turned off, in one switching period. Detailed explanation of each operating mode is given as follows:

Mode 1: the power switch S is turned on. The identical inductors, L_1, L_2 and L_3, are linearly charged in series by the input voltage source V_{in}. The diode D_2 is forward biased whereas the diodes D_3 and D_4 are blocked. As a result, the capacitor C_1 is discharged and the inductors, L_2 and L_3, are charged in series. In a charging phase, the inductor currents, i_{L1}, i_{L2} and i_{L3} increase linearly.