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Two-Phase Interleaved Boost Converter Using Coupled Inductor for Fuel Cell Applications

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Abstract

This paper investigates the benefits of directly coupled and inversely coupled inductors compared to the conventional uncoupled inductors. The coupled inductors using two phase interleaved boost DC-DC converter is used for high power and high performance applications. The advantages of the coupled inductors interleaved boost converters include increased system efficiency, reduced core size, current ripple reduction. The focus is to develop useful design equations for the operation of the interleaved boost converters under continuous conduction mode (CCM). The effects of the direct and inverse inductors has a key benefit of converter performance parameters such as inductor ripple current, input ripple current, which should be less than 4% of its nominal value of the input current for the longer life span of fuel cell and achieving stable CCM operation. The inductors are modeled in Matlab® Simulink to simulate and evaluate the performance of the DC-DC boost interleaved converter with proper design procedure of directly coupled, uncoupled and inversely coupled inductors for fuel cell applications having maximum output power of 1kW, 28.8 V and 35 A at the output voltage of 120 V.

Keywords: Interleaved boost converter; coupled inductor; ripple current; Continous conduction mode; inversely coupled; directly coupled;

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1. Introduction

Renewable energy sources is an environmentally friendly and an interesting research field due to the mitigating of the fossil fuels, which causes global warming. There are many sources of renewable energy such as Wind, Solar Photovoltaics and fuel cell. Hydrogen can be used as an input source of energy to the fuel cell to generate electrical energy. Fuel Cell is one of the promising solutions to the mentioned problems i.e. using an efficient method to utilize their energy to high system efficiency, zero carbon emission, and low audible noise [1]. Polymer electrolyte membrane (PEM) fuel cells are widely used in transportation, stationary power generation and portable devices due to their simple construction and low temperature operation, which can be used at room temperature. The output of a PEM fuel cell is an unregulated low voltage with the open circuit voltage of approximately 1 V/cell and decreases with the increase of load current. The fuel cell output voltage is stepped up by connecting a DC-DC boost converter. The output current of the fuel cell have current ripples (ΔI_{FC}), which should be less than 4 % of the input current to maintain the longer life time operation [2].

The boost converter transforms the low input power to high, which can be used for high power applications such as electric vehicles, air craft and transit bus systems [3, 4]. There are two main drawbacks associated with the conventional boost converter: 1. a high duty ratio is needed to obtain the required output voltage, which produces extremely high losses in the semiconductors devices due to their parasitic effects and 2. Conventional boost converters cannot achieve a high voltage gain due to the parasitic resistances and inductances that leads to produce high voltage drops across it [5].

By using interleaved boost converter instead of conventional one, the system voltage can be stepped up and lower current and voltage ripples can be achieved at the output of the converter. Moreover, using interleaved boost converter compared to the conventional one reduces the size of the storage devices such as inductors and capacitors. The interleaved boost converter having coupled inductors ensures reduced current ripples where the coupling coefficient is $K = \sqrt{L_1 / L_2}$ [6-9].

In this paper, the focus is to develop useful equations of interleaved boost converter under the continuous conduction mode operation (CCM). A complete simulation based comparison of directly coupled, uncoupled and inversely coupled inductors connected to the interleaved DC-DC boost converter for fuel cell applications. The coupled inductor effects the performance parameters such as inductor ripple current, input ripple current, minimum load current and output ripple voltage [10]. The uncoupled inductor needs bigger core size as compared to the coupled one but the flux is more in the former one where the flux is much reduced in the inverse coupled inductors as compared to the direct coupled. The design of the uncoupled, direct coupled and inverse coupled inductors are compared with the coupling coefficient -1< K <1 using the Matlab® Simulink.

Nomenclature

V_{fc}	Fuel cell output voltage (V)
V_o	Output voltage (V)
D	Duty ratio
L_1, L_2	Self-Inductance (H)
L_m	Mutual Inductance (H)
L_k	Leakage Inductance (H)
f_s	Switching frequency (Hz)
S_1, S_2	Switches
C_o	Output capacitor (F)
R_o	Output resistor (Ω)