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Three-Phase Interleaved Boost Converter with Fault Tolerant Control Strategy for Renewable Energy System Applications

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Abstract

This paper presents a fault tolerant control strategy for a three-phase interleaved boost converter applied to renewable energy systems. The structural and operational characteristics of the three-phase interleaved boost converter are described. By interleaving the switching circuit patterns, the input current and the output voltage ripples can be significantly decreased without increasing the switching losses, resulting in the satisfactory converter efficiency. The power and current ratings of each switching components can be lowered. The fault tolerant control strategy with Proportional Integral (PI) controller plus a phase-shift technique for the three-phase interleaved boost converter under healthy and faulty operating conditions is detailed. The simulation results are shown to demonstrate the effectiveness of fault tolerant control capability for the three-phase interleaved boost converter under normal and open-circuited switch failure operations.

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Keywords: Interleaved boost converter; Fault tolerant control; Renewable energy; Open-circuit fault; PI controller

1. Introduction

In recent years, renewable energy such as photovoltaic system becomes an increasingly important source of energies. However, the voltage levels obtained from such energy source are typically low and unregulated. Hence a suitable converter is required in order to increase and regulate the output voltage level. A dc-dc boost converter is

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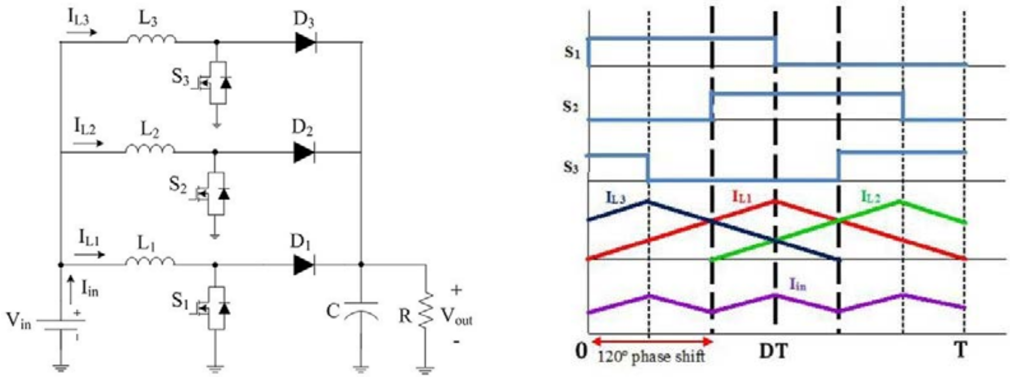
widely used for boosting the low input voltage generated from PV arrays up to a higher voltage level to supply load. An interleaved boost converter is considered as a good solution for high-power applications with low input voltage and high input current. Interleaved boost converters have been employed to increase the output power and to decrease the input current and output voltage ripples, leading to size reduction of input inductors and output filter capacitor. Compared to the classical boost converter, the interleaved boost converter provides several advantages such as lower input current ripple and output voltage ripple, higher efficiency, lower electromagnetic emission and improved reliability [1]. In addition, the reliability and continuity of operation are major concerns for renewable energy systems. It is known that the presence of faults in power converters can lead up to malfunction and consequently reduce the renewable energy system performances. In order to obtain the satisfactory system performance and to improve reliability of the converter, the fault diagnostic and fault-tolerant strategies need to be taken into account [2]. In [3] the redundancy components are added to the system to provide the improved reliability. Based on converter topology reconfiguration, the bidirectional switches are required for each phase of the multiple- interleaved boost converter in order to isolate the faulty switch and to connect to one redundant switch for the whole system [4].

In this paper, a three-phase interleaved boost converter with its fault-tolerant control strategy is investigated. The converter reliability has been improved without reconfiguring topological circuitry. By employing fault tolerant control technique, the converter can continue to operate with satisfactory performances under faulty operations. In addition, input current and output voltage ripples can be decreased, nearly the same amplitude as in healthy operating conditions.

2. Three-phase interleaved boost converter

The three-phase interleaved boost converter configuration is shown in Fig. 1(a), which consists of three identical boost inductors, L_1, L_2 and L_3, power switches, S_1, S_2, and S_3, and power diodes D_1, D_2, and D_3. Each converter phase is linked by an output filter capacitor, C, delivering power to the load, R. As can be seen in Fig. 1(a), the three-phase interleaved boost converter can be structured by three elementary boost converters interconnected in parallel. Due to interleaving operation, the input current and output voltage ripples can be significantly reduced and the power rating can be enlarged. The reduction in the size of inductors and output filter capacitor can be obtained.



(a) (b)

Fig. 1 (a) Three-phase interleaved boost converter configuration (b) Timing diagram with 120° phase shift

The input current I_{in} of the converter is the sum of the currents flowing through the inductors. Therefore, the input current can be shared among the parallel phases, leading to lower current rating of converter components. High reliability and efficiency in the system can be obtained. The power switches S_1, S_2, and S_3 operate in the interleaved manner, with the same duty cycle D and a phase-shift angle of 120°. As a result, the average values of the inductor currents I_{L1}, I_{L2} and I_{L3} are nearly the same with a phase difference of 120°. The input current and output voltage ripples can be minimized due to the ripple cancelation. The timing diagram of switching signals is shown in Fig. 1(b), when the power switches operate with 120° phase shift from each other.