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A modified boost rectifier for elimination of circulating current in power factor correction applications

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ABSTRACT

This paper develops a modified AC/DC boost rectifier for power factor correction applications. The developed rectifier topology uses fewer devices compared to semi-bridgeless type boost rectifiers, and the overall efficiency is increased due to the elimination of the circulating current provided by the inductors. Moreover, it achieves a higher power factor and better total harmonic distortion (THD) in high load conditions. The performance of the developed topology was evaluated and verified by means of simulation and hardware experimental results.

1. Introduction

Power factor correction (PFC) is required to meet power quality standards in AC/DC rectifier applications. Over the past 20 years, several topologies have been proposed for PFC applications, and many studies have preferred the boost converter type configurations because of the simpler circuits, higher accuracy, lower cost, and higher efficiency [1–3]. However, the power factor is decreased under light loads and low-input voltage conditions.

There are two ways to operate the boost mode in PFC applications: first, a boost converter followed by a diode bridge rectifier (bridge-type), and second, a front-end boost-type configuration (bridgeless). In the bridge-type converter, the total losses are too high due to a greater number of devices used in the circuit. Moreover, it produces a high-current ripple and more losses, which will degrade the efficiency of the converter for high-power applications (>1 kW). To improve the efficiency of the bridge-type converter, a soft switching technique was employed in [4–8]. In order to increase the converter efficiency, a bridgeless converter was introduced by reducing the number of devices [9–11]. Bridgeless converters are an attractive solution for high-power (>1 kW) applications where the efficiency and size are critical, but they produce electromagnetic interference (EMI) and noise. The main drawback of bridgeless topology is the floating line input with respect to the PFC switch ground and the common ground; a separate circuit is required to sense the line voltage without a line frequency transformer for sensing the line current [11–21].

To overcome the aforementioned drawbacks, a phase-shifted semi-bridgeless DC/DC converter/rectifier (SBBR) was proposed in [21]. The basic topology for the SBBR is presented in Fig. 1. This topology has high efficiency during light load conditions and reduced electromagnetic interference and is well suited for high-power applications. This converter does not share the line current through the PFC stage diode at each half-cycle [22,23]. In the conventional SBBR converter topology, the inductor currents would be circulating toward the AC source, which causes circulation current as shown in Figs. 2 to 5. This happens when one inductor gets discharged via switches and diodes and the other inductor charges. These circulating currents exhibited switching losses and conduction losses in SBBR topology, which eventually contributed to lower than expected efficiency [23]. As reported, the absence of zero current switching (ZCS) leads to lower conduction losses in SBBR, and, from the authors' knowledge perspective, there is no literature available for circulation current elimination in SBBR topology.

The basis for the proposed modified boost rectifier (MBR) topology is derived from the conventional circuit SBBR by reducing an active switch as shown in Fig. 1(b). The proposed topology consists of two

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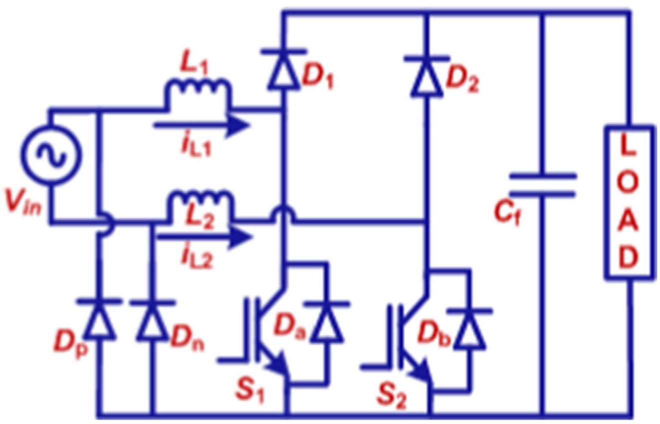

Fig. 1. Topology of the conventional phase-shifted semi-bridgeless PFC boost converter.

inductors L_1 and L_2 and active switch S_1. The two diodes (D_1 and D_2) are connected in series with inductors L_1 and L_2, respectively. This paper proposes an MBR topology that eliminates the circulating current and achieves high efficiency by reducing switching and conduction loss.

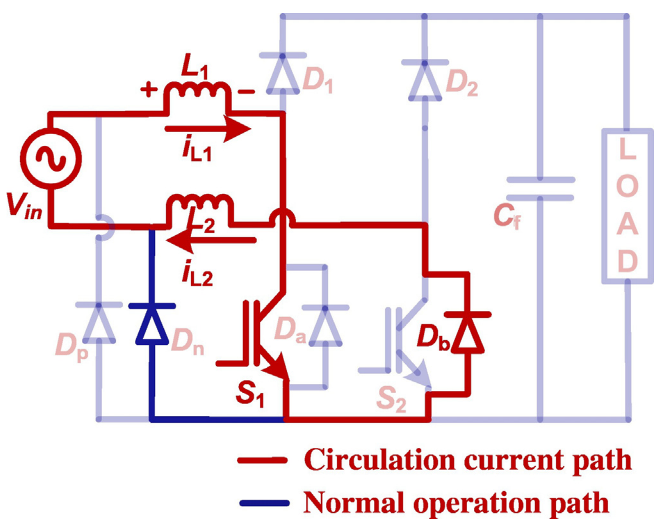

Fig. 2. Equivalent circuit for circulation current paths for conventional SBBR in the mode 1 operation.

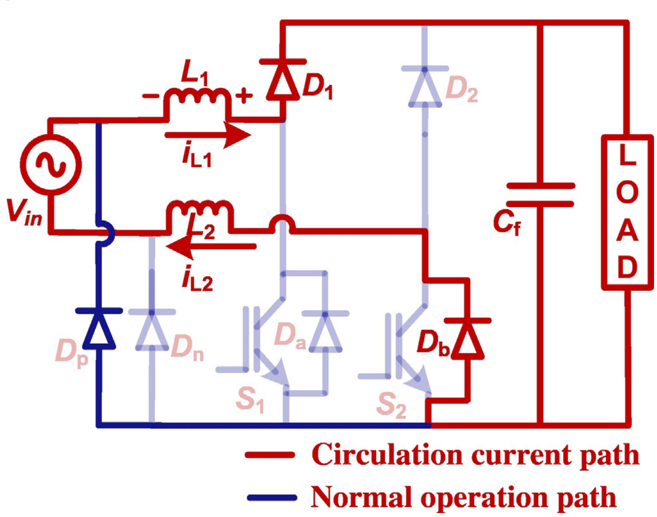

Fig. 3. Equivalent circuit for circulation current paths for conventional SBBR in the mode 2 operation.

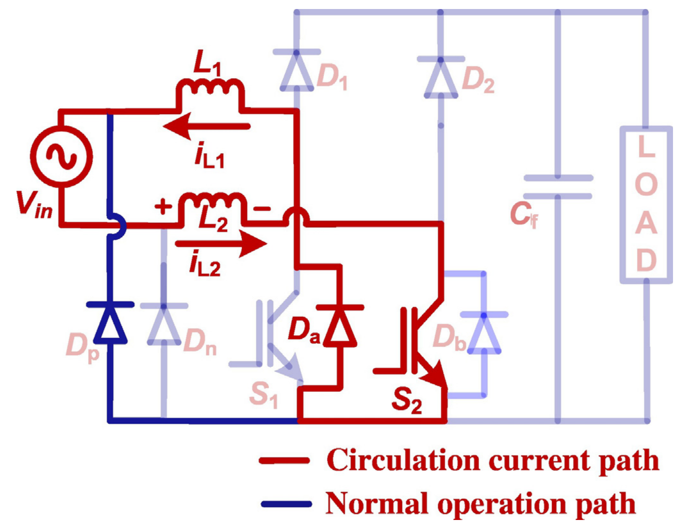

Fig. 4. Equivalent circuit for circulation current paths for conventional SBBR in the mode 3 operation.

This topology has fewer semiconductor devices as compared to SBBR, as shown in Fig. 6. The MBR is compared with the conventional SBBR as shown in Table 1. The detailed mode of operating principle for the MBR topology is explained in Section 3.

2. Circulation current in conventional SBBR

In the phase-shifted SBBR, the inductor current would circulate toward the AC source, which is generally called a “circulating current”. Usually, it occurs when one inductor gets discharged via switches and body diodes, while the other inductor charges. The current paths for circulation current during the positive half-cycle and negative half-cycle during all four operating modes are clearly indicated in Figs. 2 to 5.

The theoretical waveform of the inductor current, including the circulating current portion, is shown in Fig. 7. However, the measurement of the circulating current is difficult, as reported in [19], because it depends on input impedance, which becomes more accurate if the parasitic resistance of the switches and body diodes is considered. Thus, the procedure for determinating efficiency is difficult and the results will not be accurate. In order to accurately measure the circulating current, more sensors are required, which results in higher cost.

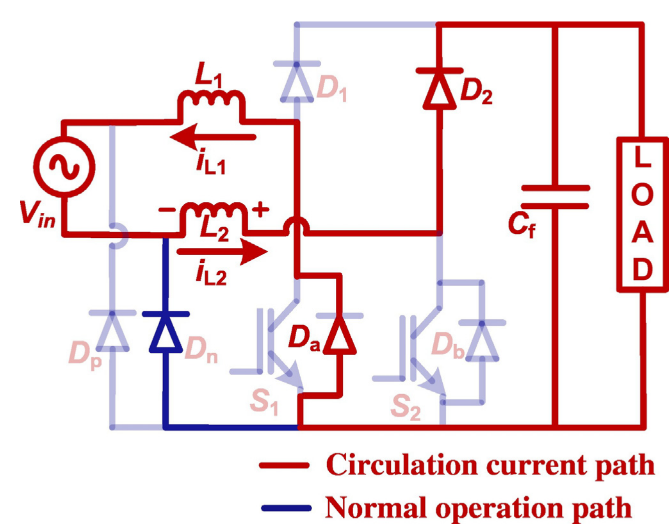

Fig. 5. Equivalent circuit for circulation current paths for conventional SBBR in the mode 4 operation.

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