Design of an H-Bridge Bidirectional DC–DC Converter with LCL Filter for High Power Battery Applications

Özhan Atmaca
Elkon Marine and Electric Technologies R&D Center
Elkon Elektrik San. Tic. A.S.
Department of Mechatronics Engineering
Sakarya University of Applied Sciences
Istanbul, Turkey
oat@elkon-tr.com

Erdeniz Erol
Elkon Marine and Electric Technologies R&D Center
Elkon Elektrik San. Tic. A.S.
Graduate School of Science and Engineering
Piri Reis University
Istanbul, Turkey
eer@elkon-tr.com

Tariq Kamal
Department of Electrical and Electronics Engineering,
Sakarya University
Sakarya, Turkey
tariq.kamal.pk@ieee.org

Murat Karabacak
Department of Electrical and Electronics Engineering
Sakarya University of Applied Sciences
Sakarya, Turkey
muratkarabacak@sakarya.edu.tr

***Abstract*—This paper provides an H-Bridge embedded bidirectional DC–DC converter with LCL filter for high power energy storage applications. Low current ripple is critical in sensitive electric devices such as batteries, two-stage photovoltaic systems and fuel cells connected at DC-bus in power electronics applications. Unlike, classical DC–DC converter, the proposed topology uses LCL filter instead of an input inductance to reduce the battery ripple current. It also reduces the value of total filter inductance, which leads to a significant reduction in copper materials, power losses, implementation cost and physical design. This study founds potential application to charge/discharge battery in high power applications, i.e., electric transportation (fast charging electric vehicles, ships) with a pre-defined reference current. Simulations and right half-plane zero analysis are performed to show the effectiveness of the proposed topology over the classical DC–DC converter**

Keywords—Bidirectional DC-DC converter, LCL-Filter, H Bridge, RHPZ, Battery charging

I. Introduction

Power Electronics technology has found its way in an extensive range of industrial, commercial, transportation and residential applications. Among the power electronics applications, DC-DC power converters have been the subject of considerable interest due to its significant involvement in renewable energy systems, micro-grids, electric transportation, smart grid, electrical drives and fast switching power supplies, etc. [1-3]. It is always vital to design highly efficient DC–DC converters to charge and discharge sensitive energy storage devices (i.e., battery, fuel cells and electrolytic capacitors) with low input current ripples. However, ripples in the input (battery) current appeared in DC-DC converters due to switching operation of power electronics switches.

There are several methods to address this problem. One way is to achieve a low input current ripple by using an extra high capacitor at the input side of converter [4-5]. Though, adding an extra capacitor at the input causes additional cost and space constraints. Other methods are to increase the value of inductance or to use passive filters. The increased of inductance provides a rapid solution, but extra copper materials, cost and bulky physical design are some of the concerns associated with it. In addition, high inductance value is mostly no preferred situation for high power systems.

Similarly, the use of passive filters causes some extra power losses and may generate a resonant behavior due to the coupling of inductors and capacitors. Some researchers have proposed interleaved operation of DC-DC converter as in [6-8]. The interleaved operation reduces output ripple due to ripple cancellation at some level among the phases, however, but a bulky inductor requirement is still a remaining concern [9]. Further, interleaved operation needs a high number of semiconductor devices. Some authors have recommended the use of tapped inductor to reduce the input current ripple [10-11], but the failure rate of inductor is high with it.

This paper proposes a new H bridge bidirectional DC–DC converter with LCL filter for high-current battery applications. LCL filter is used instead of L filter in the classical DC-DC converter. In this way, the total inductance requirement is reduced for a given constraint of a battery ripple current. As a result, the reduction of copper material occurs, which yields a light design of the circuit with low cost. Right Half-Plane Zero (RHPZ) analysis is performed for the proposed boost converter as well as for the classical DC-DC converter. It must be noted that the RHPZ leads to a high recoil in the output voltage and avoids increasing the voltage controller bandwidth, in the classical bi-directional DC-DC converter [12]. If the bandwidth is increased beyond the critical limit, instability will occur [13]. This implies that a sluggish control performance of the output voltage is an inevitable result, in the classical bi-directional DC-DC converter [14]. In the proposed converter, the RHPZ is far from the origin thanks to the LCL filter. Therefore, it is possible to increase the bandwidth of the voltage control loop much more than the conventional converter with the proposed converter, without causing the instability. Besides, the proposed topology here reduces the output voltage recoil by more than 75% as compare to the classical DC-DC boost converter.

This research is arranged as follows. Section II provides a description of the proposed converter. Section III describes the RHPZ analysis about the proposed and classical DC-DC converter. Section IV explains simulation results. Finally, conclusions are presented in Section V.

II. Description of Proposed converter

The proposed converter is recommended for high-current/power battery applications. Figs. 1 and 2 illustrate the proposed and classical DC-DC converter, respectively. The

978-1-5386-8086-5/19/$31.00 ©2019 IEEE