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A Reconfigurable Phase-Shifted Full-Bridge DC–DC Converter with Wide Range Output Voltage

by Jhon Brajhan Benites Quispe ¹ , Marcello Mezaroba ² , Alessandro Luiz Batschauer ² and Jean Marcos de Souza Ribeiro ^{1,*}

¹ Department of Electrical Engineering, São Paulo State University, Ilha Solteira 15385-000, Brazil

² Department of Electrical Engineering, Santa Catarina State University, Joinville 89219-710, Brazil

* Author to whom correspondence should be addressed.

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Abstract

This paper analyzes, designs and implements a reconfigurable phase-shifted full-bridge (PSFB) converter. It adopts the topology of the traditional PSFB converter and incorporates clamping circuits to solve some fundamental problems of conventional topology. In addition, auxiliary switches are employed for output reconfiguration, which allows expanding the output voltage range without compromising the system efficiency. Single pole double throw (SPDT) mechanical switches are used to realize series and parallel connections. In this paper, the characterization of the PSFB converter with clamping circuit and its design considerations are discussed. A 10 kW prototype with a power density of 0.485 W/cm³, 900 V input voltage and 400/800 V nominal output voltage was manufactured. The experimental results validated the analysis and confirmed the high conversion efficiency for a wide load range; an efficiency of 96.69% was obtained for the full load condition.

Keywords: phase-shifted full-bridge converter; reconfiguration; wide voltage range



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Jhon Brajhan Benites Quispe ¹, Marcello Mezaroba ², Alessandro Luiz Batschauer ²
and Jean Marcos de Souza Ribeiro ^{1,*}

¹ Department of Electrical Engineering, São Paulo State University, Ilha Solteira 15385-000, Brazil; benites.quispe@unesp.br

² Department of Electrical Engineering, Santa Catarina State University, Joinville 89219-710, Brazil; marcello.mezaroba@udesc.br (M.M.); alessandro.batschauer@udesc.br (A.L.B.)

* Correspondence: jean.ribeiro@unesp.br

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1. Introduction

The phase-shifted full-bridge (PSFB) converter is very attractive for medium- and high-power applications due to its high efficiency and power density [1,2]. It is widely used in many modern industrial fields, such as renewable energy conversion [3,4] and electric vehicle (EV) charging [5]. The phase-shift pulse-width modulation technique provides zero voltage switching (ZVS) in the primary-side switches by introducing a phase-shift angle between the half-bridge legs [6,7]. The traditional PSFB converter features simple structure, natural soft-switching, isolation capability and simple control. However, it has some well-known drawbacks that need to be resolved, such as narrow ZVS range, circulating current, duty-cycle loss, secondary parasitic oscillation and large output filter [8].

Several modified PSFB converters have been proposed to overcome the aforementioned problems [9–24]. In [9,10], the range of ZVS operation is extended by utilizing the stored energy in passive auxiliary circuits. However, these increase conduction loss and the circulating current cannot be eliminated. In [11,12], passive auxiliary circuits with adaptive ZVS energy reduce conduction loss, but the circulating current still exists. In [13,14], active auxiliary circuits with zero-voltage zero-current switching (ZVZCS) operation are adopted to eliminate the circulating current. In [15,16], the active switches are employed in secondary side and the circulating current is suppressed by adjusting the phase-shifted angle between primary and secondary switches. However, these active auxiliary circuits increase the complexity of the converter due to additional driver circuits. The hybrid-type converters proposed in [17,18] are another solution to remove the circulating current and expand the ZVS range. But many auxiliary components are required, and the improvements of cost and power density are limited. In order to mitigate the voltage oscillation across the rectifier diodes, a resistor–capacitor–diode (RCD) clamp circuit is generally

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Glauco E. R da Silva

Universidade Tecnológica Federal do Paraná 

 <https://orcid.org/0009-0006-0244-1004>

Carlos M. de O. Stein

Universidade Tecnológica Federal do Paraná 

 <https://orcid.org/0000-0001-5339-7441>

Jean P. da Costa

Universidade Tecnológica Federal do Paraná 

 <https://orcid.org/0000-0003-4742-7450>

Emerson G. Carati

Universidade Tecnológica Federal do Paraná 

 <https://orcid.org/0000-0001-6766-7190>

Rafael Cardoso

Universidade Tecnológica Federal do Paraná 

 <https://orcid.org/0000-0002-2193-2056>

Gustavo W. Denardin

Universidade Tecnológica Federal do Paraná 

 <https://orcid.org/0000-0003-3184-6095>

Jhon B. B. Quispe

Universidade do Estado de Santa Catarina 

 <https://orcid.org/0000-0003-0737-2221>

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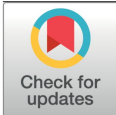
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An Isolated Active-Clamped Circuit Current-Fed Half-Bridge Converter

Glauco E. R da Silva^{✉1,*}, Carlos M. de O. Stein^{✉1}, Jean P. da Costa^{✉1},
 Emerson G. Carati^{✉1}, Rafael Cardoso^{✉1}, Gustavo W. Denardin^{✉1}, Jhon B. B. Quispe^{✉2}

¹Federal University of Technology – Paraná, Department of Electrical Engineering, Pato Branco, PR, Brazil.

²Santa Catarina State University - Electric Power Processing Group - nPEE, Joinville – SC, Brazil.

e-mail: glauco@utfpr.edu.br^{*}; cmstein@utfpr.edu.br; jpcosta@utfpr.edu.br; emerson@utfpr.edu.br; rcardoso@utfpr.edu.br;
 gustavo@utfpr.edu.br; jhon.quispe@udesc.br.

^{*}Corresponding author

ABSTRACT This paper presents an isolated regenerative active-clamped circuit designed for the current-fed half-bridge (IRACCFHB) converter. Its primary function is to reduce high voltage spikes across the main switches caused by energy stored in the leakage inductance of the power transformer using a clamping capacitor. This recovered energy is delivered efficiently to the load, maintaining the converter's high efficiency and voltage ratio. The proposed auxiliary circuit employs a single active switch with the same ground reference as the main switches, eliminating the need for an isolated gate driver. The converter achieves zero voltage switching (ZVS) during the turn-off of the main switches and zero current switching (ZCS) during the turn-on of the auxiliary switch. Energy recovery to the load is accomplished without compromising galvanic isolation due to employing a coupled inductor in the auxiliary circuit. To validate the proposed analysis and design, a 350 W prototype was implemented.

KEYWORDS Current-fed half-bridge, isolated regenerative active-clamped circuit, zero current switching, zero voltage switching.

I. INTRODUCTION

Current-fed and voltage-fed converters are common isolated topologies used in renewable energy systems. Current-fed converters, in particular, offer advantages such as smaller input current ripple and a higher transformer utilization factor, making them well-suited for microinverter applications [1], [2]. Among current-fed topologies, the current-fed half-bridge (CFHB) uses fewer active switches than the current-fed full-bridge (CFFB), resulting in lower cost and simpler construction. However, CFHBs encounter challenges such as high voltage spikes and ringing across switches during turn-off caused by the transformer's leakage inductance. These issues require the use of switches with a high breakdown voltage, which can potentially reduce converter efficiency due to the proportional increase in on-resistance with drain-source voltage.

The literature contains analyses of soft-switching operation, voltage stress on switches, and topological variations considering the converter in resonant operation. In applications such as PV, fuel cells, battery banks, and others, the current drawn from the power source should exhibit low ripple. This parameter is crucial for the proper functioning of the generation system, as it maximizes energy production and extends the lifespan of these systems, while also helping the converter comply with electromagnetic interference (EMI) regulations [3].

To mitigate issues in isolated converters, passive snubbers, and active clamps are employed to manage energy stored in leakage inductance. Passive snubbers are simpler and less

expensive but dissipate energy, thereby reducing converter efficiency. In contrast, active clamps can recover energy, improving efficiency by enabling soft-switching. This approach minimizes switching losses and overvoltages, facilitating the use of higher switching frequencies that contribute to reducing the size of the converter [4], [5].

Active-clamped circuits have been proposed for the CFHB converter. One such design, detailed in [6], is the active-clamped CFHB (ACCFHB) with a full-wave rectifier. This configuration utilizes two switches and a capacitor to clamp the voltage across the main switches, achieving zero-voltage switching (ZVS) for all switches during turn-on. However, it requires two additional drivers, which can increase both cost and volume. Further analysis of the ACCFHB under varying load and input voltages is discussed in [7] and [8]. Another variation of the ACCFHB involves an auxiliary circuit where clamping capacitor shares the ground with main switches, as presented in [9].

Additionally, [10] presents an active-clamped zero-current switching (ZCS) CFHB converter comprising a single switch, capacitor, and inductor, as illustrated in Fig. 1. This design absorbs leakage inductance energy, clamps voltage spikes, and mitigates ringing across the main switches. It enables ZCS at the turn-off for the main semiconductors and ZCS at both turn-on and turn-off for the rectifier diodes. Compared to the design in [9], this circuit operates with fewer components, supports higher switching frequencies, and reduces prototype size. The clamping action in both the main and auxiliary circuits allows the use of semiconductors