O Splines-Based Fixed-Frequency Integral Sliding-Mode Controller for PFC Rectifier

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***Abstract*—This article proposes a fast-response sliding mode controller for a semibridgeless boost converter under large and quick load fluctuations to ensure tight output voltage regulation and unity power factor correction at the line side. In this sense, a novel approach for estimating the reference current profile is presented focusing on the real-time phasor estimation via the O-splines of the discrete-time Taylor-Fourier transform. This method allows for improving the computational efficiency and dynamic performance of the estimations of amplitude, frequency, and phase of the network voltage used for the generation of the reference current profile. Several aspects of the controller design are discussed, including the choice of the sliding surface, the existence and stability conditions, and the implementation of an adaptive hysteresis band to fix the switching frequency and reduce zero-crossing distortion. Experimental results of a GaN-based prototype validate the theoretical predictions, exhibiting a power factor close to 1 and a total harmonic distortion lower than 3.2% in presence of load changes of up to 50% and changes in the output voltage set point. Several comprehensive experimental comparisons between the proposed framework and the most widely used methods recently reported in the literature are accomplished in terms of transitory and steady-state responses. The robustness of the proposed control approach is experimentally demonstrated under sag conditions and a wide operating range of the input voltage.**

***Index Terms*—Active rectifier, adaptive hysteresis band (AHB), discrete-time Taylor-Fourier transform (DTTFT), GaN switches, nonlinear control, O-splines, power factor correction (PFC), sliding mode control (SMC).**

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I. Introduction

In RECENT years, many countries, policymakers, and research centers have recognized the growing need to develop more efficient and safe electrical systems, making them more reliable and environmentally friendly [1], [2]. In this scenario, circuits with automatic power factor correction (PFC) are one of the key technologies to reduce harmonic distortion and optimize the efficiency of the network infrastructure [3], [4], [5].

Currently, grid-connected equipment must guarantee a high power factor (PF) and low harmonic content according to the limits established by the IEEE 519 and IEC/EN 61000 standards [6], [7]. A comparison of different PFC boost converters is summarized in Table I.

The control targets in PFC rectifiers are emphasized to achieve a sinusoidal input current in phase with the network voltage and precisely regulate the dc output voltage. Although the development of PFC rectifier control systems has been extensively covered in previous studies [8], [9], [10], [11], two research gaps still remain: 1) the development of robust control systems with wide operational range; and 2) improving the synchronization methods to reduce the harmonic content, zero-crossing noise, and computational burden.

The sliding mode controller (SMC) grants stability and robustness to the PFC circuit against parameter, line voltage, and load uncertainties over a wide operating range and can be implemented with a straightforward control rule [2], [12], [13], [14]. However, the practical application of SMC in PFC converters is limited by the nonconstant switching frequency [15], [16], [17], [18], [19]. Variable operating frequency increases the size and cost of filters, inductors and heat sinks, as well as increases power losses.

To deal with the adverse variable switching frequency, several possible solutions have been proposed. These include the incorporation of constant timing functions or circuitries, increasing the complexity and cost of the overall system [20], [21]. The SMC with fixed frequency can also be implemented indirectly using pulse width modulation (PWM), but this approach reduces the robustness of the closed-loop system [4], [17], [22]. This work applies an adaptive hysteresis band (AHB) that allows operation with a fixed switching frequency without affecting the robustness of the SMC and without adding complexity to the system [16].

Aiming to synchronize the active rectifiers with the network voltage, the converter controller often embeds an active synchronization algorithm such as the phase-locked loop