SDU Faculty of Engineering

PhD Defence

by

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Title:

Development of Low Parasitic Loss Aluminum Electrolytic Capacitors

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Abstract
With respect to the green transition, the efficiency of power electronic systems has attracted attention in recent years. Electric vehicles, renewable-energy converters, industrial drives and countless other technologies are all moving towards higher performance and lower losses. While the development of wide band gap devices, such as Silicon Carbide (SiC) and Gallium Nitride (GaN) set a milestone for those applications, they have also introduced new challenges that need to be overcome. Higher switching frequencies, steep current transients and thermal stress do not only affect new power semiconductors but also passive components, such as capacitors. For a fast frequency response and low losses, ceramic and film capacitors are well known, whereas aluminum electrolytic capacitors (AECs) offer higher energy density and a low capacitance-to-cost ratio. Due to their parasitic loss behavior, which leads to higher thermal stress and lower efficiency, AECs are frequently substituted with film capacitors in high-frequency applications.
This thesis addresses these limitations through new measurement methods and capacitor designs that significantly reduce the equivalent series inductance (ESL) and resistive losses inside AECs. The work is structured around four studies, all contributing to the overall development of low-loss AECs.

The first study develops a new measurement fixture for high frequency measurements. The new fixture has been tested to provide stable and reliable measurements up to 1 MHz. In particular the development of low ESL capacitors require a reliable measurement set-up for high frequencies.

The low ESL design from the second study relies on a new tabfoil geometry which has been evaluated through a finite element analysis (FEA), prior to manufacturing. The FEA has proven that a significant reduction in ESL is possible. After manufacturing the 450 V, 58 µF prototype, the ESL has been improved by 25 % compared to the standard layout. The prototype uses a commercially available high-voltage (HV) electrolyte which is going to be replaced in the next study, in order to lower the equivalent series resistance (ESR).

The HV-electrolyte is substituted in the third study, by PEDOT:PSS a conductive polymer. Using the same winding from study two introduced the challenge of impregnation. Since, large windings tend to clog their fiber pores, and therefore a new precoating process has been developed. This had the effect of reducing the ESR significantly by 10 times compared to the standard HV-electrolyte.

To reduce the ESR even further the fourth study investigates a separatorless design to omit the losses induced by the paper separator. The same conductive polymer as in study three has been used, while changing the winding geometry to a stack design. This reduced complexity and comparability, making the process easier later on. The separator substituted by PEDOT:PSS protects the anode through its high viscosity and reduced the ESR by a factor of 12, while maintaining breakdown stability up to 554 V.

Together these four studies demonstrate that both ESL and ESR can be significantly reduced by combining optimized geometry and advanced polymer electrolytes. This thesis and the presented concepts offer a pathway towards more compact, thermally robust and energy efficient converters, contributing directly to the technological foundation required for the green transition.

Keywords: Aluminum Electrolytic Capacitors (AEC), Equivalent Series Inductance (ESL), Equivalent Series Resistance (ESR), PEDOT:PSS Electrolyte, Polymer Impregnation, Parasitic Elements, Green Transition Technologies