Gallium Nitride Transistors (GaN) Based Multilevel DC-DC Converters

Abstract

Resonant switched-capacitor DC-DC converters represent a dynamically evolving class of power electronic devices. Novel topologies are continuously being developed, providing not only high voltage gain but also its effective attenuation capabilities, while maintaining high efficiency of this process. These characteristics are particularly significant in applications such as micro photovoltaic installations and supercomputer power systems. Moreover, by eliminating inductive components from the energy conversion process, these converters feature compact dimensions, low weight, and the capability to operate over a wide ambient temperature range. The aforementioned properties of resonant switched-capacitor converters significantly enhance their application potential and make them competitive with conventional converters, whose operation relies on the properties of inductive components used in their construction.

The first stage of work related to the preparation of this doctoral dissertation involved the development of an innovative topology of a multilevel high voltage gain direct current converter (HVGDCC). This converter is characterized by a sixfold voltage gain, the ability to regulate the output voltage in seven discrete steps, a relatively low number of transistors, and low voltage stress on individual switches. Moreover, the proposed converter exhibits high energy conversion efficiency, and its operation in Zero Voltage Switching (ZVS) mode further reduces losses by minimizing those associated with the output capacitance (C_{oss}) of the transistors.

As part of the conducted research, a comparative analysis was carried out on two units of converters that were built according to the developed topology of a high voltage gain direct current converter (HVGDCC). The first of the examined converters were built using CoolMOS transistors, while the second was designed based on the implementation of CoolGaN switching devices in the power circuit. The aim of this analysis was to identify differences in the operation of multilevel resonant switched-capacitor converters resulting from the use of different types of transistors. Those differences were observed in the current and voltage waveforms of individual components and the efficiency characteristics of the examined DC-DC converters.

For each analyzed version of the HVGDCC converter, a simulation model was developed in the Matlab-Simulink environment to verify the operational concept of the designed system. The simulation studies conducted on the HVGDCC-CoolMOS and HVGDCC-CoolGaN models focused on validating their functionality and comparing the power losses occurring in individual components of both developed systems. The simulation analysis was summarized by plotting the efficiency characteristics recorded for both models operating in zero current switching (ZCS) and zero voltage switching (ZVS) modes, with a load value that varied over a wide range throughout the simulation time. During this series of simulations, advanced transistor models were employed that accounted for both their static and dynamic parameters. The dynamic parameters were defined using complete characteristics extracted from the technical documentation of real switching devices. The simulations were performed in the Matlab-Simulink environment using the "Parallel Computing Toolbox" package.

The positive results of the simulation studies led the author of this doctoral dissertation to decide on the construction of experimental models for both analyzed converters and to continue

research on physical systems. As a part of the conducted laboratory work, numerous oscillograms were recorded, illustrating waveforms crucial for analyzing the operating principles of the investigated converters and assessing the switching phenomena occurring in systems operating in both zero current switching (ZCS) and zero voltage switching (ZVS) modes. The final stage of the laboratory studies for each analyzed converter involved recording its efficiency characteristics while operating in both ZCS and ZVS modes.

As a result of the conducted research, it was determined that the developed topology operates in accordance with the assumptions established during the conceptual phase. The converter itself exhibits a sixfold voltage gain factor, reduced voltage stress on individual switches, and high efficiency. Additionally, an analysis of the oscillograms recorded during the testing of both converters revealed that the current waveforms in the system utilizing CoolGaN transistors demonstrate significantly fewer oscillations associated with the charging and discharging of the transistors' output capacitances (C_{oss}). Moreover, the amplitude of these oscillations is considerably lower compared to those observed in the converter built with CoolMOS transistors.